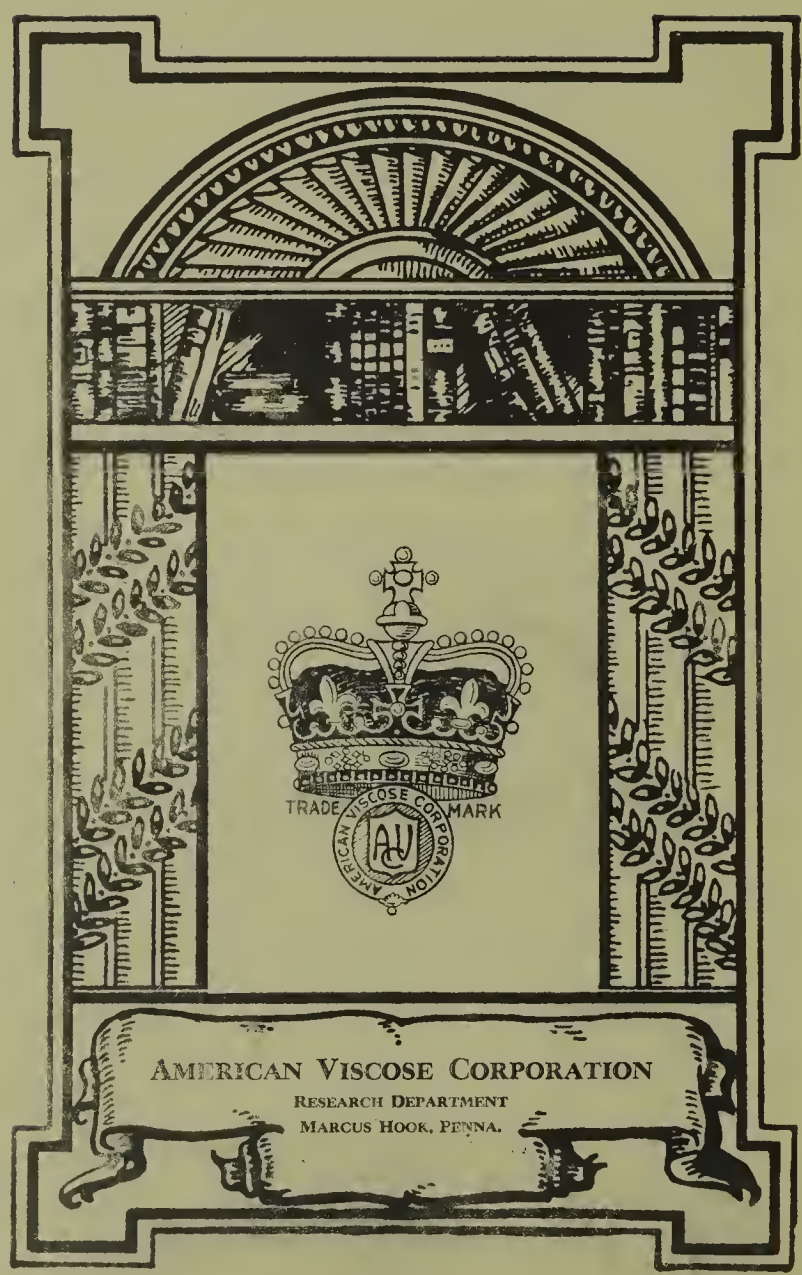
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TRANSACTIONS OF THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

THE RELATIONS OF THE GEOLOGICAL SURVEY TO CHEMICAL ENGINEERING

By GEO. OTIS SMITH [1]

Read at the Washington Meeting, December 5, 1923

The National Research Council has used a phrase that well describes what may perhaps be the whole purpose of this meeting: "mobilizing scientific facts for industrial uses," which is a good text for talk and a better program for work. Research under governmental auspices, if properly planned, aids industry; and that scientific bureau is truly successful which directly contributes to engineering. To test the extent of this helpful relationship it is appropriate for this Institute to review the agencies at work.

The Federal Geological Survey touches the work of the chemical engineer primarily as adviser on raw materials. Study of the sources of mineral raw materials was preeminently the job given to this service forty-odd years ago. At that time the annual withdrawals of raw materials from Nature's warehouse were small—measured in value they were less than one-twelfth those of recent years. In even more striking contrast was the ignorance of the contents of that warehouse: both qualitative and quantitative knowledge of our mineral resources was lacking, and the geologist could only refer to "their wonderful variety and yet unmeasured amounts." However, it was already keenly realized that these mineral commodities constitute the basis for industrial enterprise and that authoritative and accurate information concerning them must be available for use in promoting the arts.

Thus it happens that along with its explorations of mountain range and desert and canyon, which contributed to the settlement of the West and to the development of mining and irrigation and power-

[1] Director, United States Geological Survey.

generation, the Geological Survey during all these years has kept in touch with the industrial growth of the East and has tried to keep step with the chemical engineer as he has entered and occupied new fields. New processes and new products have created, almost overnight, demands for new materials, and the realization that the mineralogical curiosity of one decade may be the valuable ore of the next has taught the geologist not to limit his inventory of rocks and minerals to those which have a known present utility. He is indeed a bold prophet who pretends to forecast either the probability or improbability of future usefulness of any raw material. There is a bit of warning in the circumstance that an early list of useful minerals published by the Geological Survey did not even mention bauxite, now the principal ore of aluminum.

Perhaps the chief service that the Geological Survey renders to industry is its prompt mobilization of facts relating to these mineral raw materials. An inventory of our resources of some minerals may be found ready at hand, as, for example, phosphate rock, which the Survey has investigated from early days, first in the South and later in the West, where a public reserve of high-grade rock of more than five billion tons has been disclosed. Salt, gypsum, oil shale, borax, mica, clay, and magnesite are other nonmetallic minerals whose distribution and mode of occurrence have been described in Survey publications in sufficient detail to make the supplies available as needed in the arts. In August, 1914, the call for a domestic supply of many commodities that had previously been imported gave the Geological Survey the opportunity to serve as agent in bringing consumer and producer into touch with each other, and in this clearing-house activity the Survey handled facts on minerals as diverse as ichthyol and flint pebbles, kaolin and radium, sulphur and magnesite, high-calcium limestone and tungsten, mercury and glass sand, antimony and graphite. And when, for example, the Navy Department sent over a hurry-up call for a map showing the distribution of low-sulphur coking coal, the information needed was at hand as the product of the Geological Survey's routine investigations.

Too often, however, a critical demand for information reveals a shortage of facts, so that an intensive study or an extensive exploration, or both, have to be made before the demand is fully met. Such an investigation was the search for potash and nitrate, which began a

dozen years ago and has led our geologists in turn to the desert basins of Nevada and California, to the mountains of Utah and Wyoming, to the saline lakes of Nebraska, and more recently to the plains of western Texas and southeastern New Mexico. To-day one potash plant at Searles Lake in California has survived the post-war deflation, and in Texas there is good promise of commercial deposits of potassium sulphate at minable depths. Other examples of special search for needed minerals were the war-time explorations for manganese, pyrite, chrome, and platinum. Then, too, the search in ordinary times for new sources may have the purpose of lowering the cost of an essential material, such as asbestos or arsenic. The acute demand for arsenic last year, and again this year, made useful the facts that had been collected when arsenic was a drug on the market, but these are not enough, and information must be developed to show reserves of arsenic ores to supplement the by-product arsenic.

These contributions of the Federal geologists have been made possible only as the chemists of the Geological Survey have aided the geologists by examinations and analyses of specimens and samples; nor has this routine determinative work been unproductive as research. The contributions of Hillebrand to our knowledge of the distribution of the rarer elements, the development of analytical methods by Hillebrand and his associates, Clarke's tables of atomic weights, and especially his monumental handbook—the Data of Geochemistry—are some of the products of the Survey laboratory that illustrate its usefulness to the chemical engineer.

The Geological Survey rendered pioneer service in supplying industry with full knowledge of the mineral fuels, but in later years this field has been occupied jointly by the Survey and the Bureau of Mines, which very properly, with its intensive study of fuel utilization, has stood nearer to the chemical engineer.

This summary of the raw-material inventories available in the files or reports of the Geological Survey would be incomplete without mention of the most abundant and yet most essential mineral of all—water. More and more we are realizing that water supply may be the determining factor in the distribution not alone of urban population but of industrial opportunity. Facts regarding the quality as well as the quantity of water available are of prime value in planning the development of chemical industries. And when, six years ago,

so many classes of scientific facts were called to the colors, it was both gratifying and enlightening to witness the mobilization of the Geological Survey's records of many years' gaging of stream flow and analysis of ground and surface waters. The location of hospitals and cantonments, the planning of munition plants, the allocation of an inadequate supply of condenser tubes, and the location of power plants were among the war-time problems that called for specific and detailed facts such as were found in the Survey's files.

If the curve of industrial progress is to continue an upward trend in the immediate future at all comparable with that of the past four decades, we can foresee an ever-increasing need of marshalling all the facts relating to raw materials. It is the unexpected find that gives zest to the search, and it is the emergency call from the engineer that inspires the scientist to be prepared.

Discussion

Dr. John C. Olsen: I should like to ask Dr. Smith what bentonite is.

Dr. George Otis Smith: It is a clay used in making antiphlogistine, in packing horses' hoofs, and in adulterating many things. It is a clay in collodial condition. If you put some of this dust in with water, it immediately becomes a gel, and so it has many industrial possibilities.

Dr. Olsen: Is there a lot of it?

Dr. Smith: We are finding it all over the country; in the West in Wyoming and Montana, and now some is found in the East. It is a volcanic glass, laid down in different periods of geologic time, probably as dust falling from the air, and that has decomposed into a very fine grained clay.

A Member: In reply to Dr. Olsen's question, I will say that we have been doing some experiments in bentonite ourselves, in the laboratory, and bentonite has very valuable properties in decolorizing oil. It is far superior to the best Fuller's earth that we have ever obtained—of course, we give it a preliminary treatment—but it is remarkable in its properties for decolorizing cotton seed and peanut oil and other things. We have not completed our experiments, but we know that it will find a great use in decolorizing oils, and there is an adequate supply of it.

Dr. Edward Bartow: The value of the surveys of water supplies made by the Geological Survey is very great. I have one incident in mind where the information had been gathered, but was not used. When the Air Field was located at Bellville, Illinois, they did not take into consideration the fact that the water from wells would be salty, though the information was in the Geological Survey reports. After drilling two wells which would give 500,000 gallons each, they found the water so salty that they could not use it for anything except watering streets. Such information is usually available in the Geological Survey reports and the reports should be consulted.

Dr. Howard: I have also done quite a little work with bentonite in our laboratory. Isn't it also used as a filler for soap?

Dr. Smith: Yes; I have even heard of it being used as a filler for candy [laughter].

President Howard: Well, it would be harmless.

Dr. McCormack: One of the most interesting uses for bentonite is in removing the ink from old paper. The ink is removed and the pulp re-used.

Dr. Smith: We probably have had more inquiries recently in regard to that use than for any other purpose.

Dr. Heinberg: In regard to uses for bentonite, in Canada they use it by mixing it into the form of small cakes, for eating purposes.

THE RELATION OF THE BUREAU OF MINES TO CHEMICAL ENGINEERING

By D. A. LYON

Read at the Washington Meeting, December 5, 1923

President Howard: The next paper is "The Relation of the Bureau of Mines to Chemical Engineering," by H. Foster Bain, Director of the Bureau of Mines. I understand that the author is unable to be here to-day, having been called to the same Senate committee meeting which Dr. Smith was called to attend, and so Dr. Lyon will present his paper.

Dr. D. A. Lyon: Dr. Bain did not give me a paper to present, and so I can only extend to you his greetings and express his regret at not being here. However, I will endeavor to say a few words on the subject which was assigned to him, namely, "The Relation of the Bureau of Mines to Chemical Engineering."

As you can readily understand, the work of the Bureau of Mines must necessarily be limited to those activities defined by the Act of Congress under which the Bureau was created. That Act definitely states that the Bureau shall have to do with the prevention of waste and the increase of efficiency in mining, metallurgical and allied industries.

The organization of the Bureau is divided into two branches, namely, the Research Branch and the Operating Branch. As the Operating Branch has to do principally with the routine administrative work of the Bureau, it will not be necessary in this connection to discuss the work of this branch.

The Research Branch is again divided into divisions, namely, the Divisions of Mining, Metallurgy, Fuels, Mineral Technology, Petroleum and War Minerals Supply.

Very little laboratory work is done by the Bureau in Washington, this work being done at its various experiment stations located throughout the country. Mr. Fieldner has already spoken of one phase of the work which is being carried on at the experiment station

at Pittsburgh. All the stations have assigned to them some particular line of activity. At the station at Pittsburgh, which is the largest station, attention is given almost altogether to coal, as likewise at the station at Urbana, where the work is carried on in cooperation with the Mining Department of the University of Illinois. At Columbus, Ohio, in cooperation with the Ceramics Department of the Ohio State University, the work is confined entirely to ceramics. In the Mississippi Valley the Bureau has a station which, in cooperation with the Missouri School of Mines, at Rolla, is giving its attention to the problems met with in the treatment of the lead and zinc ores of the Mississippi Valley. At the Southern Station, which is conducted in cooperation with the University of Alabama, at Tuscaloosa, attention is given to the mining and beneficiation of iron ores. At Minneapolis, in cooperation with the School of Mines of the University of Minnesota, attention is given to the mining and utilization of iron ores. At Salt Lake City problems are studied which are met within the mining and metallurgical treatment of the low-grade and complex ores of lead and zinc. This work is carried on in cooperation with the Department of Metallurgical Research of the School of Mines of the University of Utah. At Seattle the Bureau carries on practically all of its work on electro-metallurgy and is also studying those problems met with in the washing of the coals of that part of the country, as the problems found there are different from the problems which present themselves in the washing of the coals of the Middle West and East. The work at Seattle is carried on in cooperation with the College of Mines of the University of Washington. At its station at Reno, Nevada, where the work is carried on in cooperation with the Mackay School of Mines of the University of Nevada, the Bureau is making a study of the problems met with in the mining, milling, and metallurgical treatment of rare and precious metals. At New Brunswick, N. J., a study is being made of the problems met with in the mining and beneficiation of non-metallics. This work is carried on in cooperation with Rutgers College. At the Bureau's station at Bartlesville, Okla., attention is given to the problems which are met with in the petroleum industry. At Tucson, Arizona, where the work is carried on in cooperation with the Mining Department of the State University and the Arizona State Bureau of Mines, attention is being given to the problems met with in the mining and metallurgical treatment of copper ores in general, and especial attention

has been given to the working out of the fundamentals of the chemistry of hydro-metallurgical processes for the treatment of low-grade copper ores, and especially the carbonate and oxidized ores which can not be successfully concentrated by ordinary gravity concentration processes or by flotation processes. At Berkeley, in cooperation with the College of Mines and the Department of Chemistry of the University of California, research work is carried on which has to do with the working out of the fundamental chemical data needed in connection with the investigations and research problems which are conducted at the several stations of the Bureau carrying on work on non-ferrous metallurgy.

The Bureau also has a station at Fairbanks, Alaska, which is really a service station. As the Government owns most of Alaska, the Secretary of the Interior approved of the plan that the Bureau do service work in that Territory. This work more nearly approaches the work of the consulting engineer than does any other work of the Bureau. This is due to the fact that Alaska does not have many consulting or chemical engineers, or even assayers, at the present time, and for this reason the Bureau does work there of a nature which it does not do elsewhere.

The Bureau in its chemical engineering work is desirous of carrying on such work as will result in securing the fundamental information and data needed by various industries and confines its work as much as possible to securing these fundamental data. The Bureau prefers to do its work in cooperation with state institutions and with the industries, for if it is working in cooperation with a particular industry it knows the industry is interested in that particular work. Moreover, after the work is finished the Bureau is more certain of the results being used by the industry if the work is a cooperative piece of work than if it does it itself and publishes the results in a bulletin which may be put on a shelf and never looked at. However, it often is necessary to do work which does not seem especially applicable at the time, but which in the long run proves very useful to some branch of mining, metallurgy, or allied industry. All of the work of the Bureau is, of course, for the public generally, though the Bureau prefers to carry on its work in cooperation with a group of smelters or mines rather than with the individual company, and the results of that work come back to the public in the form of bulletins

and technical papers. The Bureau always reserves the right to publish the results of cooperative work.

This, in brief, is an outline of the work of the Bureau of Mines as related to chemical engineering. As before stated, I have no paper to present, and I hope that Director Bain may be able to be here later and address you.

THE PHYSICAL PROPERTIES AND COMBUSTIBILITY OF COKE IN RELATION TO ITS PRODUCTION AND USE[1]

By A. C. FIELDNER[2]

Read at the Washington Meeting, December 5, 1923

Introduction

There is perhaps no phase of fuel technology that has aroused more discussion or regarding which there is more difference of opinion than the properties of coke most suitable for blast furnace and other metallurgical uses. The older textbooks whose authors were less hampered by experimental evidence had much more positive opinions on the subject than the books of to-day. The older specifications insisted on large massive pieces of silvery luster and metallic ring with as low as possible a content of moisture, ash, sulphur, and volatile matter. The first by-product coke was rejected without trial by the blast furnace man because it was smaller, and lacked the much-prized silvery luster and metallic ring. To-day the furnace man who must use beehive coke considers himself handicapped in making good consumption and capacity records. Experience has shown that the greater uniformity in size and quality of by-product coke far outweighs the esthetic considerations that favored the use of beehive coke. The metallurgical industry now realizes that practically nothing is known regarding the optimum physical properties of metallurgical coke, and that reliable information on this subject is needed from a number of points of view. The furnace man should be able to specify the kind of coke that is best for his purpose without imposing any needless requirements that reduce the oven output and sacrifice a portion of the gas and by-product yield. It is probable that many coals now thought to be inferior for production of suitable metallurgical coke can be used when we have a real knowledge of the

[1] Published by permission of the Director, Bureau of Mines, Department of the Interior.

[2] Superintendent and Supervising Chemist, Pittsburgh Experiment Station, Bureau of Mines.

relation of the properties of coke to its performance in use. Excellent records have been made in the last two years in a furnace using coke of inferior physical properties made from Illinois coal, judging by the usual standards.

These are the reasons for the Bureau of Mines taking up a fundamental investigation of the properties of coke and the influence of these properties on blast furnace reactions and operation.

Standardization of Methods of Testing

The first step in this research was the standardization of the methods of testing. This was done in cooperation with Committee D–5 on Coal and Coke of the American Society for Testing Materials. The methods for chemical analysis had previously been standardized and were generally recognized as satisfactory, but there were no generally recognized standards for judging the physical properties. Depending on the method of carbonization and the selection of the coal, coke may vary widely in its physical properties. It may be light or heavy, porous or dense, soft or hard, brittle or tough, weak and friable, or strong and coherent. The pieces may vary in shape and structure from large, massive, blocky pieces to small, fingery pieces full of checks. It may ignite easily or with difficulty, and it is believed by many that the reactivity with oxygen and carbon dioxide varies greatly in different cokes—i.e., some coke has greater combustibility or burns faster than other cokes. Many of these physical properties are so interrelated that it is exceedingly difficult to devise tests for their separate evaluation. And even in such cases where tests have been devised their meaning in terms of operation is obscure. The work of standardization was therefore doubly difficult because of doubt as to the interpretation and value of the results in practical use.

The first step in this investigation was to study and standardize, if possible, the physical tests in most common use. These are the shatter test for determining the resistance of coke to breakage on handling; the tumbler or "hardness test" designed to give a relative value for the resistance of coke to mechanical attrition in the furnace; true and apparent specific gravity from which the porosity or per cent cell space may be computed; combustibility or rate of oxidation in air and the so-called "solubility in carbon dioxide" or rate of reaction with carbon dioxide. The last two tests are chemical rather than physical.

True and Apparent Specific Gravity

No particular difficulties were involved in working out procedures for reproducible determinations of the true and apparent specific gravity, from which the porosity or per cent cells of the coke can be readily computed. Careful consideration was given to the procuring of representative samples of considerable size, a matter of importance because of the great variation in porosity of coke from different parts of the oven. The work on specific gravity and porosity was done at the Pittsburgh Experiment Station and the results obtained were published in a paper by Selvig and Parker.[3]

Shatter and Tumbler Tests

The shatter and tumbler or "hardness" tests were studied at the Southern Experiment Station of the Bureau of Mines at Tuscaloosa, Ala., by Kinney and Perrott,[4] who made many tests on a wide variety of coke, giving particular attention to the size and selection of the samples for test, the method of screening, and the agreement of results of duplicate determinations.

Shatter Test.—In the shatter test a 50-lb. sample of coke was dropped four times from a height of six feet upon a steel or cast-iron plate. The material was then screened over a 2-inch square mesh screen, and the percentage of the original sample remaining on the screen was reported as the shatter test result.

Critical study of this procedure with many samples showed:

(1) A 50-lb. sample of coke is too small to be representative. So great is the variation of different pieces of coke that at least three and preferably five tests should be averaged. A single determination may be in error from 2 to 13 per cent; the average of three to five tests should be correct to within 1 to 2 per cent.

(2) Large pieces of coke about half the width of the oven gave the most uniform and reproducible results.

(3) More reproducible values were obtained in screening the coke after the shatter test, by putting all the pieces through the screen which would go through in any position, than by shaking the screen.

(4) The use of a series of screens—namely, 2-inch, 1½-inch,

[3] Selvig, W. A., and Parker, W. L., "The Determination of Specific Gravity of Coke," *Chem. Met. Eng.*, 28, 547–50 (1923).

[4] Kinney, S. P., and Perrott, G. St. J., "The Shatter and Tumbler Tests for Metallurgical Coke," *J. Ind. Eng. Chem.*, 14, 926–41 (1922).

1-inch, and ½-inch—gives a much better indication of the resistance of the coke to shattering than the single 2-inch screen now in use.

Shatter test values for different by-product and beehive coke based on percentage over 2-inch screen varied from 37 to 60 per cent, enough to be significant as regards breakage, but yet unknown as regards relation to blast furnace operation. It is a test in which the coke oven operator will be more interested than the blast furnace superintendent.

Tumbler or "Hardness" Test.—A 25-lb. sample of 3 to 2-inch coke was placed in the apparatus and the drum revolved 1,200 times at the rate of 20 r.p.m. The so-called "hardness" number is the percentage of original sample remaining on a ¼-inch screen. Some blast furnace men think this test is a measure of the relative resistance of cokes to mechanical attrition in the blast furnace. Perrott and Kinney's [5] work showed that this test as made in a 30-inch diameter drum was influenced by two principal factors in determining the amount of coke broken to pass a 0.25-inch screen—namely, impact and abrasion. Tests made with a sample of 3-inch lumps produced more fines than tests with samples of 1-inch lumps, due presumably to lesser crushing effect of small lumps falling from the top of the drum upon the material near the bottom. This analysis led to the further conclusion that a coke which shattered easily was broken up early in the test period to small pieces which had a relatively small crushing effect on dropping across the revolving drum and thus produced little fines from impact. This action evidently took place in the tests with Illinois, Benham, and Alabama No. 6 cokes as shown in Table I; these cokes gave very low shatter tests, but high hardness numbers. Further inspection of Table I shows that some cokes with high shatter test figures show hardness numbers equally high to cokes of low shatter test. Evidently the hardness test as now practiced measures an uncertain combination of impact and abrasion.

In Fig. 1 are plotted the screen analyses of seven cokes after passing through the tumbler test. The entire range of the hardness figures for seven radically different cokes is from 70.6 to 77.5 per cent, a total range of 7 in a value whose probable error of a single determination is approximately one. Fig. 1 also shows that the hardness values of these cokes is quite different in the larger sizes. If we take the per cent on ¼-inch screen as our criterion of "hardness,"

[5] Loc. cit.

TABLE I

PHYSICAL PROPERTIES OF COKE SAMPLES

Coke	Shatter	"Hardness"		Specific Gravity		Porosity
		A	*B*	True	Apparent	
Alabama No. 1	70	70	——	1.75	.96	45
" " 2	74	73	89.1	2.10	1.02	52
" " 3	69	68	89.4	1.96	1.00	49
" " 4	72	67	——	1.91	.83	57
" " 5	69	71	90.6	2.00	.99	51
" " 6	64	74	90.2	2.13	1.15	46
" " 7	72	71	88.8	1.91	.98	49
" " 8	70	74	90.4	1.98	1.05	47
" " 9	70	74	92.3	2.04	1.14	44
" " 10	70	68	——	1.92	.98	49
" " 11	77	73	——	1.97	.81	59
Benham	59	73	88.4	1.85	.91	51
Connellsville	66	71	92.0	1.89	1.02	46
Illinois	42	78	90.5	1.84	.87	53
Pitch coke	78	76	92.9	2.00	1.16	42

A. Method using 3–2-inch coke; result reported as percentage remaining on a ¼-inch screen.

B. Method using ¾–¼-inch coke; result reported as percentage remaining on a ⅙-inch screen.

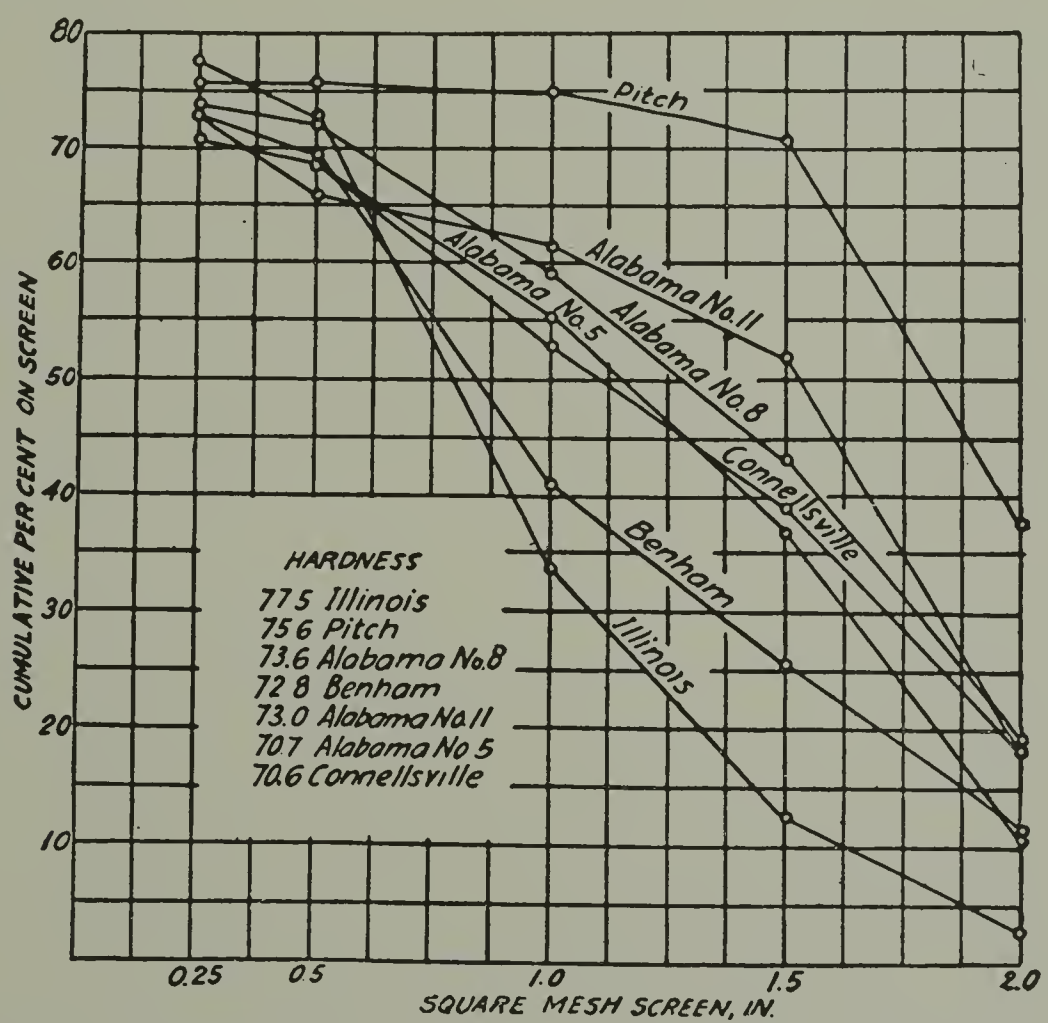

FIG. 1. Screen Analysis of Cakes after Tumbler Barrel Test.

then the Illinois coke is the hardest, since 77.5 per cent remains on this screen as compared to 70.6 per cent for a Connellsville beehive coke. On visual inspection the blast furnace superintendent would say that the Connellsville coke was incomparably harder than the Illinois coke. However, referring again to Fig. 1, we see that only 15 per cent of the Illinois coke passed over the 1½-inch screen as compared to 38 per cent for the Connellsville coke and 70 per cent for the pitch coke. The amount of ¼ and ½-inch material produced does not vary much for widely different cokes, but the percentages of material on the 1-inch and the 1½-inch screens do vary greatly and in the same order as the shatter test values. With such additional screening the tumbler test becomes of some value, but does not give any new or additional information on physical properties not shown by the ordinary shatter test.

To eliminate the effect of impact Perrott and Kinney[6] modified the tumbler test by first crushing the coke sample to pass through a ¾-inch screen and remain on a ¼-inch screen. The hardness number was the percentage remaining on a ⅙-inch screen. The results which are given in Table I vary from 88.4 per cent for Benham coke to 92.9 per cent for pitch coke, a total range of 4.5 units. Evidently the resistance to attrition of small pieces of coke rolling on each other and dropping through a distance of 30 inches is very similar for all coke, and probably of much less significance in the use of coke in furnaces than is the breakage of the larger pieces.

Further work may be done on some modification of the barrel tumbler apparatus and method, but from present information this test does not show sufficient differentiation in physical properties of coke to be capable of general interpretation into blast furnace performance; therefore this test has not been accepted as standard.

Combustibility

While the previously described research work on the tests for physical properties of coke was in progress at the Pittsburgh and Southern Experiment Stations of the Bureau, P. H. Royster and T. L. Joseph, metallurgists at the North Central Experiment Station, Minneapolis, Minn., were studying blast furnace reactions in miniature furnaces at this station, and in commercial furnaces whenever opportunity offered. They suggested that so little was known of

[6] Loc. cit.

the mechanism of the processes inside the blast furnace that the furnace operator could not know what physical properties to specify even if we worked out a complete system for their evaluation. We spent several weeks interviewing coke oven and blast furnace operators in the Birmingham, Pittsburgh, and Chicago districts, and became convinced that neither the furnace man nor the coke operator knew the optimum physical and chemical properties of blast furnace coke in quantitative scientific terms. According to their best opinions, "a good blast furnace coke (1) must have sufficient mechanical strength to resist crushing and abrasion in the furnace; (2) must be low in ash and sulphur; (3) must be of uniform size; (4) must be resistant to the oxidizing action of the carbon dioxide in the stack gases; and (5) must burn very rapidly at the tuyeres."[7]

There is much discussion in the literature along these lines, but no definite quantitative experimental data, and indeed it is very difficult to get such data. As stated by Perrott and Sherman:[8] "The furnace operator depends almost entirely on observing how the cokes behave in the furnace itself and here he has an extraordinarily difficult problem in judging the relative merits of the coke from blast furnace operating data.

"In general the value of a coke is judged by the weight of coke required to produce a ton of iron, and by the tons of iron produced per day. This is determined in turn by the ratio of coke to ore in the furnace, the iron content of the ore, and the volume of blast blown per minute. The first and last of these factors are determined by the blast furnace operator who is guided by the regularity of descent of the stack, by the appearance of the combustion zone at the tuyeres, and by the composition and apparent temperature of iron and slag. The operator must keep his furnace in continuous operation, and must keep his ratio of fuel to ore sufficiently high to prevent freezing of the furnace.

"It is evident that the performance of a furnace depends to a great measure upon the operator's opinion as to the minimum amount of coke which may be used. When to the operator variable we add the variables of different ore burden, furnace lines, grades of iron, and uncertainty as to the true analysis and weight of materials going into the furnace, we evidently have a difficult problem in attempting

[7] Perrott, G. St. J., and Sherman, R. A., "Reactivity of Coke in Relation to Blast Furnace Operation," *Eng. Soc. of W. Pa.*, 1923.

[8] Loc. cit.

to isolate the effect of various kinds of coke by making use of data obtained at different furnaces."

Research on Combustibility of Coke

At the present time most blast furnace men believe that cokes vary in combustibility and that such variations have an important influence on the rate of driving (i.e., output), and the amount of coke required to produce a ton of iron. The definitions of combustibility vary from "that variable property of cokes by virtue of which it is possible to maintain a higher tonnage and produce a ton of iron with a smaller amount of one coke than of another," to "the speed at which the carbon molecules in the coke combine with oxygen under given conditions." Likewise, several different types of "combustibility" tests are in use, namely (*a*) a laboratory tube test, in which a weighed amount of pulverized coke is heated to a definite temperature in a current of air or oxygen for a definite time. The loss in weight is the relative combustibility; and (*b*) a salamander test, in which a cylindrical shell of sheet iron is filled with the coke, the mass ignited and allowed to burn in natural or forced draft.

In a paper presented at the June, 1923, meeting of the American Society for Testing Materials, Perrott and Fieldner[9] have shown that neither of these tests give a satisfactory measure of combustibility as scientifically defined, namely, "the rate of the chemical reaction of carbon combining with oxygen." The two large errors that vitiated both methods are the use of definite weights in place of volumes of coke, and lack of accurate control of rate of air or oxygen flow over the coke.

It was suggested that the small furnace designed and used by Kreisinger, Ovitz and Augustine[10] for studying combustion in fuel beds was free from the objections raised to the tube and salamander tests.

This furnace, with some slight modification as shown in Fig. 2, was used at the Pittsburgh Experiment Station by Sherman and Blizard[11] for determining the combustibility of four kinds of blast

[9] Perrott, G. St. J., and Fieldner, A. C., "The Properties of Metallurgical Coke," *Proc. Am. Soc. Testing Materials,* 23, II, 475–93 (1923).

[10] Kreisinger, Henry, Ovitz, F. K., and Augustine, C. E., "Combustion in the Fuel Bed of Hand-fired Furnaces," Bureau of Mines Technical Paper 137, 1917, pp. 15–16.

[11] Sherman, Ralph A., and Blizard, John, "Combustion of Blast Furnace Cokes in Fuel Beds," *Trans. Am. Inst. Min. Met. Eng.,* 1923.

furnace coke, the results of the investigation and full description of the apparatus being reported at the February meeting of the A. I. M. M. E. in New York. Further tests have been made since on the

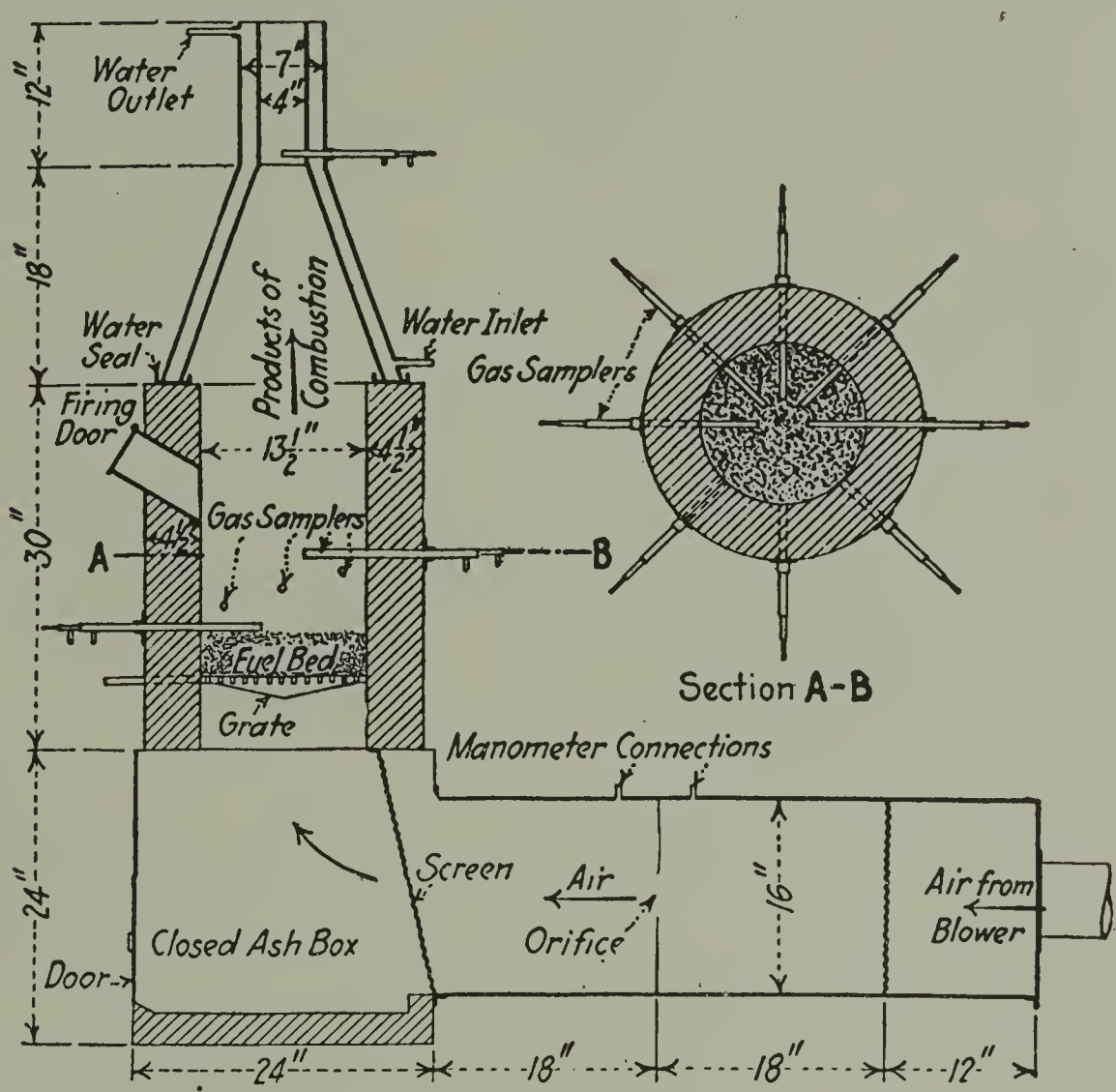

FIG. 2. Cross-section of Experimental Furnace.

effect of size, and on petroleum coke, pitch coke, and lignite char. A part of these latter tests are reported by Sherman and Kinney[12] in *Iron Age*.

COMBUSTIBILITY BY THE KREISINGER FURNACE

A brief résumé of the work to date on combustibility with the Kreisinger furnace will be of interest. This furnace has a grate area of one square foot, is mounted on a wind box so that the rate of air supply can be accurately measured and controlled, and is provided with radial holes around the side of the furnace through which gas samples are taken with water-cooled tubes and through which tem-

[12] Sherman, Ralph A., and Kinney, S. P., "Combustibility of Blast Furnace Coke," *Iron Age*, 111, 1839–44 (1923).

peratures are read with an optical pyrometer. The cokes for test were carefully sized, the depth of the fuel bed and the rate of air supply were maintained constant for all similar tests. Fresh charges of fuel and removal of ash were made in small increments so as to keep the fuel bed at a constant level. Numerous gas samples were taken at intervals of 1½ inches from the grate. The average results of these analyses are shown in the lower half of Fig. 3. The cokes

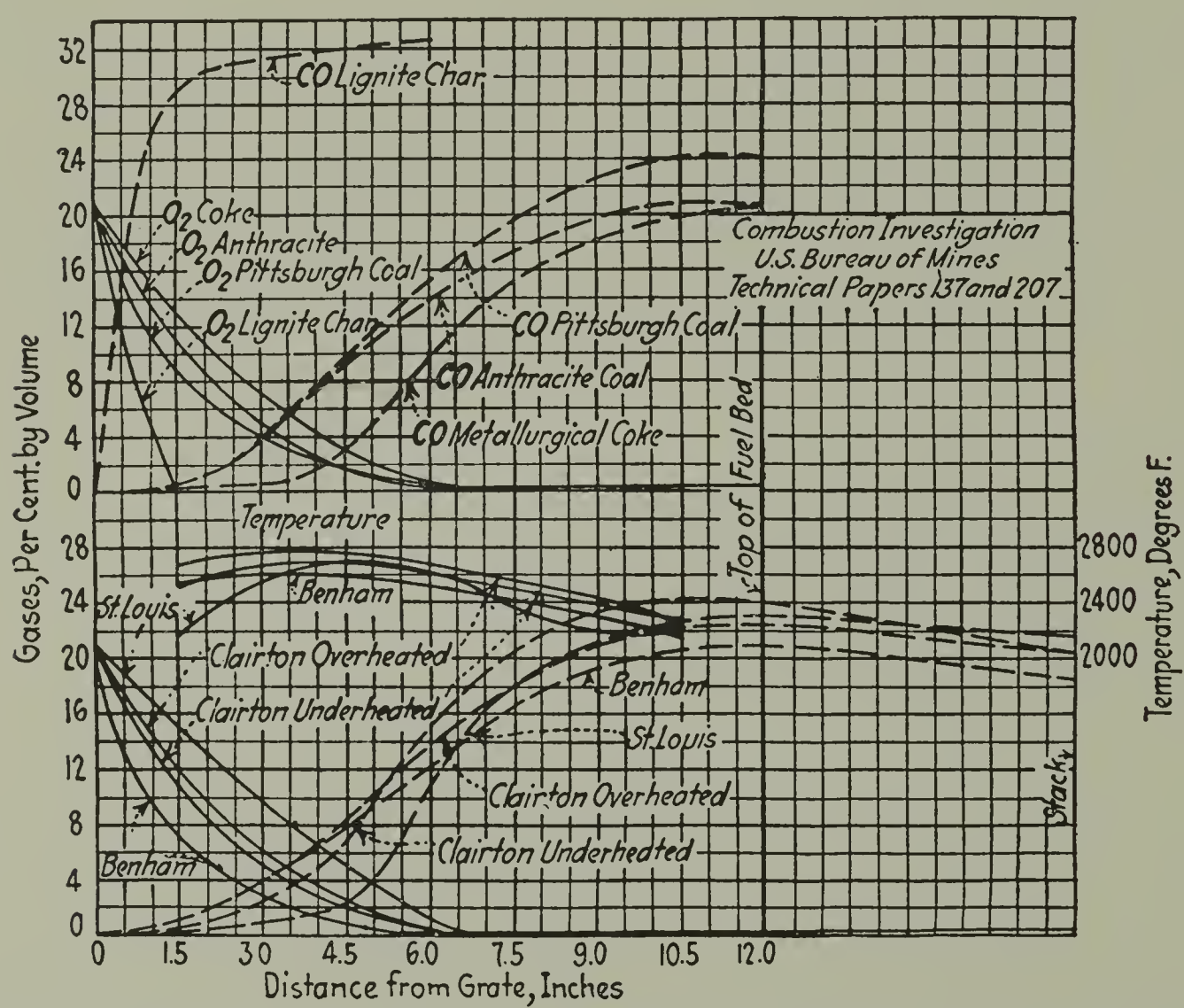

FIG. 3. Mean O_2 and CO Content of Gases and Temperatures in Fuel Beds.

were burned at approximately 25 lbs. per sq. ft. per hour, sized to between 1½ inches and 1 inch. The upper half of the curve gives results of some earlier tests by Kreisinger on different fuels.

It will be observed that in no test was the combustion fast enough to proceed to complete reduction to carbon monoxide within the space of the 12-inch fuel bed used in all the tests. The relative combustibility of the coke, therefore, can not be measured by the extent of the combustion zone as in the blast furnace hearth. However, the relative combustibility as regards oxygen may be measured by the distance

above the grate where oxygen is completely consumed, or for the entire 12-inch fuel bed, by the percentage of carbon monoxide in the gases leaving the fuel bed. In the blast furnace combustion zone we are concerned with complete conversion of solid to gaseous carbon, the end product being carbon monoxide. From this standpoint the percentage completeness of combustion at any point is represented by the following expression

$$\frac{CO_2 + CO}{2CO_2 + CO + 2O_2}$$

since a gas containing $XCO_2 + YCO + ZO_2$ will give on complete reaction with carbon at blast-furnace temperatures $2XCO + YCO + 2ZCO$. We, therefore, may express the relative combustibility of the fuels at any point of the fuel bed in terms of completeness of combustion, by substituting the gas analysis from that point in the above expression. Fig. 4 shows the mean combustibility in per cent completeness of combustion of various fuels at varying distances from the grate. The curves show that near the grate where the principal reaction is $C + O_2 = CO_2$ the combustibility varies with the different cokes, but that about 6 inches above the grate it is about the same, 60 to 65 per cent; between this point and the top of the fuel bed the curves again separate somewhat, but approach to within a range of approximately 5 per cent at the top of the fuel bed. It should be noted that the cokes do not show the same order of combustibility in oxygen as they do in carbon dioxide; however, the tests are, as yet, too few in number to explain these differences, or to draw any general conclusions as to the effect of ash content, porosity, time of coking, etc.

The size of the fuel does have a marked influence and the high combustibility of the lignite char is largely due to the fact that it would all pass through a ½-inch screen, whereas the cokes were from 1 inch to 1½ inches in size. In future tests more attention must be given to size. Tests are now in progress with pitch coke, petroleum coke, and a number of varieties of beehive and by-product cokes. The experimental difficulties are great. From the limited data now at hand it appears that the size of the coke is likely to prove a much greater factor in determining the extent of the combustion zone in a blast furnace than the porosity, condition of coking, or kind of coal, except as these factors influence the size of the coke when it reaches the tuyere zone.

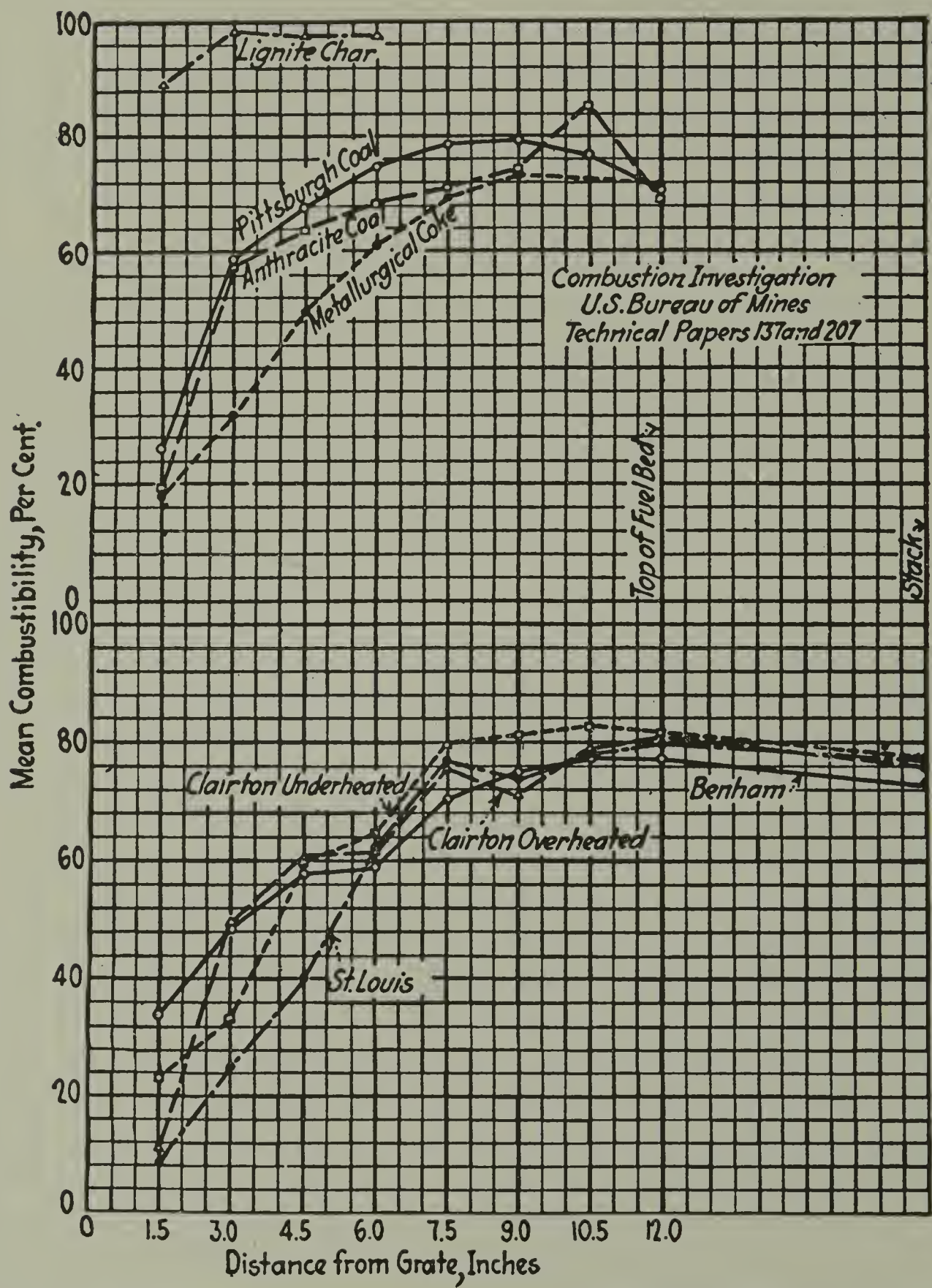

FIG. 4. Mean Combustibility of Various Fuels at Varying Distances from the Grate.

Extent of Combustion Zone in Blast Furnace

At the same time that Sherman and Blizard were investigating the combustibility of coke in the Kreisinger furnace at the Pittsburgh Experiment Station the problem was attacked from another angle by Perrott and Kinney[13] at the Southern Experiment Station of the Bureau in the Birmingham, Ala., district. Their method consisted in taking hearth gas samples at intervals of four to six inches on a line from the tuyere nose to the center of the furnace through water-cooled sample tubes inserted in the tuyeres. The cooperation of blast furnace operators was obtained and experiments were completed at six blast furnaces in the Birmingham district, six in the northern district at Pittsburgh, Pa., Youngstown and Columbus, Ohio, and at East St. Louis, Ill. Also one test was recently made at a charcoal furnace. Much credit is due to Messrs. Perrott and Kinney for carrying out the arduous experimental work involved in driving a 2-inch diameter water-cooled sampling pipe into the tuyere of a blast

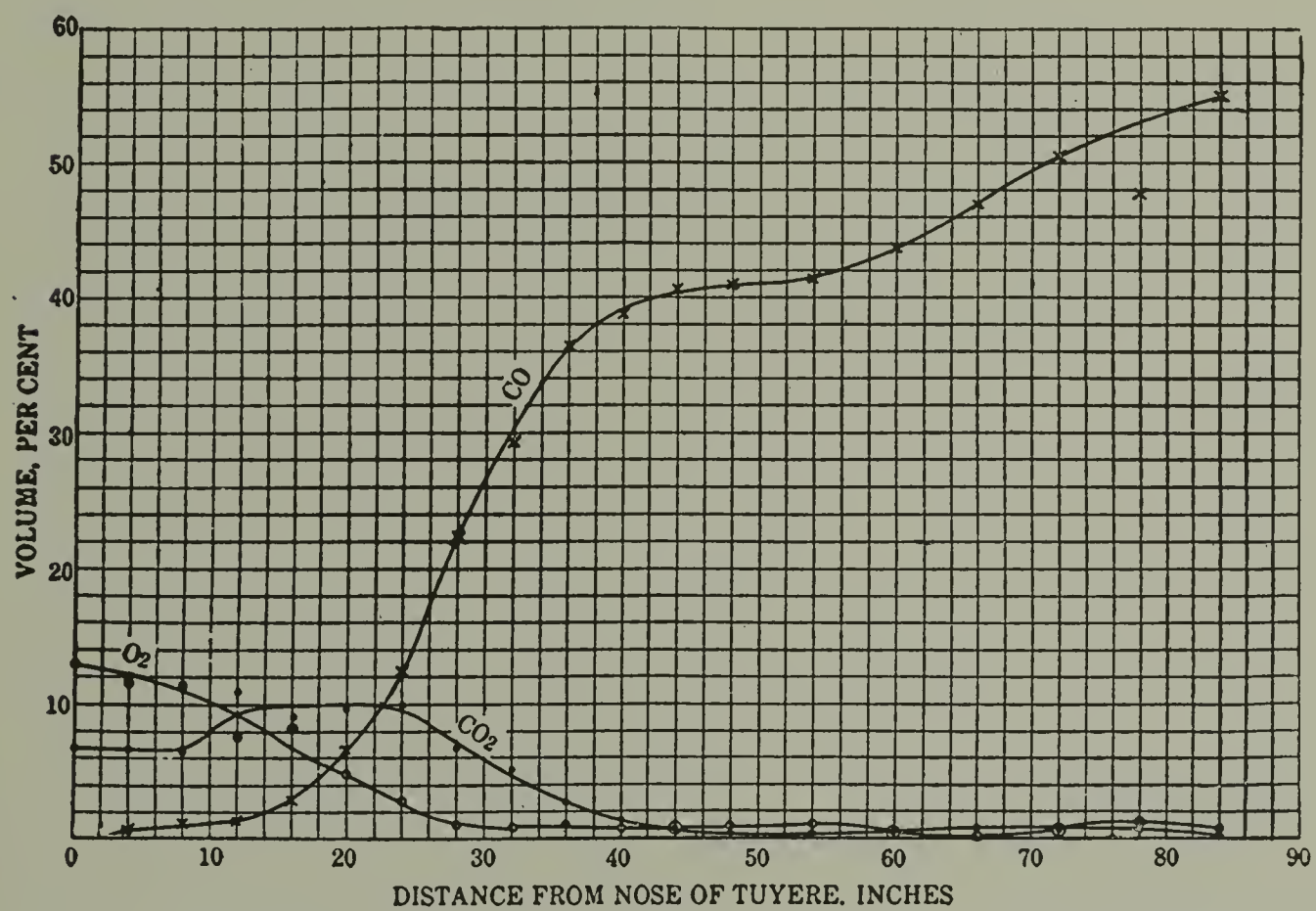

Fig. 5. Combustion of Coke in Blast-Furnace Hearth. Average data from ten furnaces.

[13] Perrott, G. St. J., and Kinney, S. P., "Combustion of Coke in Blast-furnace Hearth," *Trans. Am. Inst. Min. Met. Eng.*, 1923.

furnace in full blast. There was also real physical danger in the work. Happily there were no casualties.

Fig. 5 shows the average gas analyses from 10 furnaces. The separate plots for each furnace are not reproduced here, but are given with complete details of the first part of this work in Perrott and Kinney's [14] paper referred to above. There was but little difference in the curves for the different furnaces even when the coke was quite different in composition. Fig. 5 shows that combustion in the hearth is very rapid, the oxygen diminishing to practically zero at 24 to 30 inches from the tuyeres, while carbon dioxide disappears at 32 to 40 inches. The oxygen of the blast has completed its work of gasifying carbon at about 36 inches from the tuyeres, and the combustion zone occupies about 200 cu. ft., or but 1 per cent, of the furnace volume.

Perrot and Kinney found that differences in the extent of the combustion zone at the several furnaces were a matter of inches only, and bore no apparent relation to the composition or physical structure of the coke. Contrary to the general opinion of blast furnace men this investigation showed that the combustion zones of furnaces operating on low coke per ton of iron were approximately the same size as of those furnaces operating on high coke composition. The differences observed in the individual gas analyses of the various furnaces were too small and irregular to correlate with any known change in chemical composition or physical structure of the coke. The results of this investigation confirm the tentative conclusions from the combustibility tests in the Kreisinger furnace—namely, that the rate of combustion of all kinds of coke in the tuyere zone of the blast furnace is so nearly the same that it has no appreciable influence on the furnace economy or operation.

Blast furnace men do not accept these conclusions yet and have suggested further work to secure confirmatory evidence; this is now being done by Mr. Kinney in the Birmingham district, where a blast furnace superintendent, who is much interested in this investigation, is relining a furnace and is putting in special sampling holes on the sides of the furnace between the tuyeres and the stack. This arrangement will permit taking of gas samples and temperatures on a number of levels and permit following the course of the chemical reactions above the hearth zone.

[14] Loc. cit.

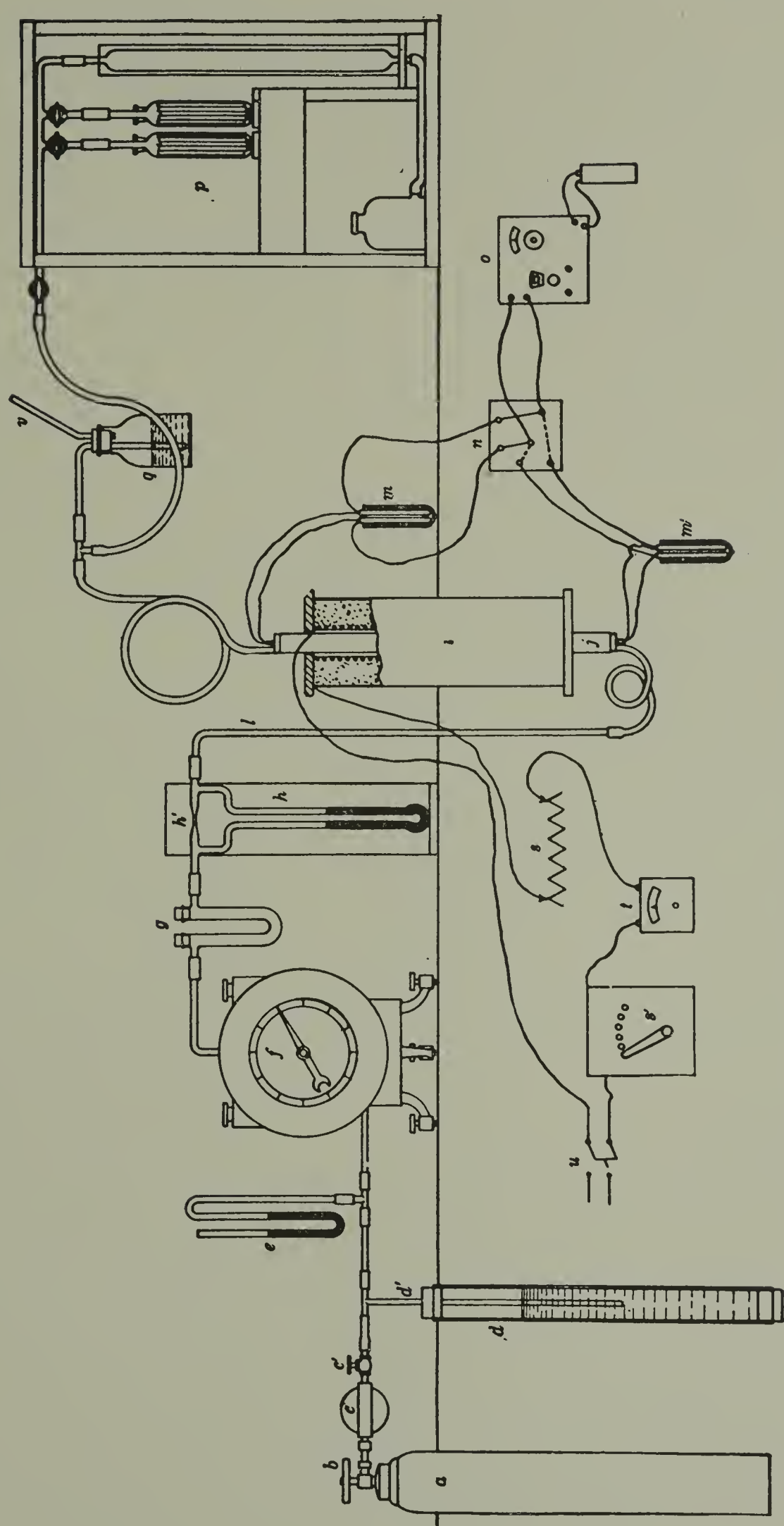

FIG. 6. Apparatus for Determining the Solubility of Coke in Carbon Dioxide.

Oxidation or Solution by Carbon Dioxide

Many furnace men believe that a coke should be such that it will resist oxidation by carbon dioxide in the shaft of the furnace above the tuyere zone; such oxidation is termed "solution loss." According to their ideas a good coke is one which resists oxidation by CO_2 in the stack, but is very reactive in the tuyere zone. To obtain data on the relative reactivity of various cokes with carbon dioxide at stack temperatures, Perrott and Fieldner,[15] of the Bureau of Mines, developed a laboratory test (see Fig. 6) in which a constant stream of carbon dioxide is passed through a 2-inch layer of 6 to 8-mesh coke contained in a quartz tube (1-in. internal diameter) at a rate of 1 liter per minute for one hour. The temperature of the coke is maintained at 1,000° C. throughout the test. The result is reported as grams of carbon oxidized during the test.

A comparison of the test results with actual operating data is shown in Table II. In this test we find a considerable difference in the reactivity of the cokes to carbon dioxide at 1,000° C., but unfortunately it shows no definite relation to the percentage of carbon oxidized above the tuyeres, as calculated from the operating data of the furnaces using these cokes. Charcoal, for example, shows a weight loss by the laboratory test of 100 times that of Connellsville coke, but shows a slightly greater percentage of its total carbon burned at the tuyeres than Connellsville coke. Here, again, the expectations and beliefs of the blast furnace operator are not realized. He, however, retains his belief that combustibility, reactivity with CO_2, porosity, nature of the carbonaceous material, volatile matter, etc., are of prime importance in coke and insists that the coke producer shall run his ovens regardless of the by-product yield to the single end of producing the kind of coke that he believes is needed, and to prove his point he is inviting the Bureau's research men into his plants and offering every cooperation. He realizes the need of chemical engineering research on the mechanism of the blast furnace reactions.

Research in Experimental Blast Furnace

The Bureau of Mines has realized for some time the need of an experimental blast furnace large enough to reproduce the conditions of commercial furnaces and small enough to be operated at a reason-

[15] Loc. cit.

TABLE II

RELATIVE REACTIVITY OF COKES WITH CO_2

Furnace	Type of Coke-oven	Coal		Tons of Iron per Day	Coke per Ton of Iron	Carbon Burned at Tuyeres per 100 Lb. Carbon Chgd. as Coke	Density of Coke		Porosity	Loss by CO_2 on Standard Test	
		State	Seam				True	Apparent		Grams	Relative
1	BH	Pa.	Pgh.	220	2800	75	1.89	1.02	46	0.7	10
2	BH	Ala.	Pratt	322	2807	76.5	2.13	1.15	46	0.9	13
3	BH	Pa.	Pgh.	580	1960	77	1.90	0.98	48	0.9	13
4	SS	Ala.	Brookwood & Meldale	258	3160	78	2.00	0.99	51	1.1	16
5	SS	Ala.	Mary Lee	260	2800	72	1.96	1.00	49	1.1	16
6	SS	Ala.	" "	356	3345	77	1.92	1.05	45	1.1	16
7	K	Ala.	Pratt	418[a]	1900	78	2.04	1.14	44	1.2	17
8	K	Ala.	"	476	2750	78	2.01	1.13	44	1.2	17
9	K	Pa.	Pgh.	512	1960	76	1.90	0.98	48	1.3	19
10	K	Pa.	"	525	2100	78	1.99	1.04	48	1.5	21
11	R	Ill.	No. 7	515	1770	73	1.84	0.87	53	3.0	43
Charcoal fur-furnace[b]		Herraag, Sweden	Charcoal[c]	—	1600	79	—	—	—	7.0[c]	100
Charcoal fur-fornace		Ala.	"	50	2080	78	—	—	—	7.0	100

a Forty-five per cent scrap.
b From Richards, "Metallurgical Calculations," p. 246.
c Average of several samples of wood charcoal made in the U. S. A.

able cost under controllable conditions, and recently our hopes have approached realization in the construction of an experimental furnace of 36-inch hearth diameter and 31 feet high in cooperation with the State of Minnesota at the North Central Station of the Bureau of Mines at Minneapolis, Minn. This furnace is arranged for taking gas samples, temperature measurements, and samples of stock at various points. With this furnace the influence of the various physical and chemical properties of coke can be studied under controlled conditions and ultimately we hope that information will be obtained on which the essential specification for metallurgical coke can be based, and needless requirements that may restrict the production of valuable by-products in the coking process may be eliminated.

Acknowledgments

The author makes full acknowledgment to the various members of the Bureau of Mines staff who have conducted the research investigations on coke from whose reports this paper has been prepared.

Following is a list of the reports thus far published:

Essential Factors in the Formation of Producer Gas, by J. K. Clement, L. H. Adams, and C. N. Haskins, Bureau of Mines Bulletin No. 7, 1911, 58 pp.

Foundry Cupola Gases and Temperatures, by A. W. Belden, Bureau of Mines Bulletin No. 54, 1913, 29 pp.

Metallurgical Coke, by A. W. Belden, Bureau of Mines Technical Paper No. 50, 1913, 48 pp.

The Determination of Moisture in Coke, by A. C. Fieldner and W. A. Selvig, Bureau of Mines Technical Paper No. 148, 1917, 13 pp.

Hygroscopicity of By-product Coke, by W. A. Selvig and B. B. Kaplan, *J. Ind. Eng. Chem.*, 12, 783–84 (1920).

Study of the Reactions of Coal Sulfur in the Coking Process, by A. R. Powell, *J. Ind. Eng. Chem.*, 12, 1069–1077 (1920).

Sulfur in Coke, by A. R. Powell, *Proc. Eng. Soc. W. Pa.*, 36, 611–640 (1920–21).

Standard Methods of Laboratory Sampling and Analysis of Coke, American Society for Testing Materials—Standards—1921, pp. 787–97.

Standard Specifications for Foundry Coke, American Society for Testing Materials—Standards—1921, pp. 752–54.

Tentative Method of Shatter Test for Coke, *Proc. Am. Soc. Testing Materials*, 22, [I], 822–24 (1922).

Shatter and Tumbler Tests for Metallurgical Coke, by G. St. J. Perrott and S. P. Kinney, *J. Ind. Eng. Chem.*, 14, 926–41 (1922).

Combustion of Blast Furnace Cokes in Fuel Beds, by Ralph A. Sherman and John Blizard, *Trans. Am. Inst. Min. Met. Engrs.*, 1923.

Combustibility of Coke, by Ralph A. Sherman, *Fuels and Furnaces,* 1, 97–100 (1923).
Combustibility of Blast Furnace Coke, by Ralph A. Sherman and S. P. Kinney, *Iron Age,* 111, 1839–44 (1923).
Combustion of Coke in Blast Furnace Hearth, by G. St. J. Perrott and S. P. Kinney, *Trans. Am. Inst. Min. Met. Engrs.,* 1923.
Quantitative Determination of Sulfur Forms in Coke, by A. R. Powell, *J. Ind. Eng. Chem.,* 15, 951–53 (1923).
The Forms of Sulfur in Coke. A physico-chemical study of the sulfur held by carbon at high temperatures, by A. R. Powell, *J. Amer. Chem. Soc.,* 45, 1–15 (1923).
Forms of Sulfur in Coke and their Relations to Blast-furnace Reactions, by A. R. Powell, *Trans. Am. Inst. Min. Met. Engrs.,* 1923.

Chemical Division,
Pittsburgh Experiment Station,
Bureau of Mines,
October 17, 1923.

Discussion

Mr. Robert T. Haslam: As Mr. Fieldner has pointed out, there are only two possible reactions between coke and dry air. The Bureau of Mines has already shown that there is very little difference among the various fuels as far as the reaction between oxygen and carbon is concerned. If I remember correctly, the only fuel that acts peculiarly is lignite, which reacts with oxygen about twice as rapidly as ordinary coke. With regard to the other possible reaction, the reduction of the CO_2 formed from the first reaction by additional coke, it should be borne in mind that if you crush coke down to a size suitable for laboratory tests, you change the character of the surface and the test may not be comparable to the action in a blast furnace. I do not think such laboratory tests will show anything of importance, and I think the only reliable results on the solubility of coke by carbon dioxide will have to be obtained on a full-sized sample. The comparison of the solubility of coke on full-sized samples in the laboratory is difficult. In going over this question of combustibility of coke I find that few people really agree as to what is meant, and I have not yet found a blast furnace superintendent who could define what he means by that phrase "combustibility." He probably means low fuel consumption. It may be that the coke when heated in a blast furnace breaks up, due to thermal expansion. If we could actually bring our coke down to the tuyere level in the same condition

as it goes into the top of the furnace, a laboratory test might be satisfactory. But it seems to me there are some physical properties of coke, such as its ability to withstand temperature changes, which are more important than any of the chemical reactions studied so far.

Dr. G. O. Smith: In the old days it was said that a large part of the test of coke was its ability to support the burden. I wonder if that is now considered?

Mr. A. C. Fieldner: Little if any attention is now given to testing coke for its ability to support the burden in a blast furnace.

Belden[1] states:

"Attempts have been made to use the compressive strength of a coke for calculating the height of furnace burden that the coke is capable of sustaining. This practice is not warranted, as the following simple statement will show:

"One cubic foot of coke weighs approximately 28 pounds, 1 cubic foot of ore and flux weighs approximately 115 pounds.

"If the charge is mixed in the approximate proportion of 3 parts by weight of ore and flux to 1 part by weight of coke, then

28 pounds coke	=	1.00 cu. ft.
86 pounds ore and flux	=	0.75 cu. ft.
114 pounds charge	=	1.75 cu. ft.

"One cubic foot of charge therefore weighs 65 pounds. Let it be assumed that the weight of the charge is evenly borne and that the height of the furnace is 95 feet, then the weight on each square foot at the base is 65 multiplied by 95, or 6,175 pounds per square foot, or about 43 pounds per square inch. Even the poorest cokes would doubtless show a crushing strength much in excess of this figure."

Dr. Haslam has mentioned one of the most important considerations in the physical properties of coke—namely, the probable changes in these properties during its descent in the furnace, especially the change in size.

We are planning to study these factors with the use of the experimental blast furnace at the Minneapolis Station of the Bureau of Mines.

Mr. Wilson: I should like to ask if the coke developed from Illinois coal, at East St. Louis, has been used in blast furnaces? It seems to me that that is such an ideal location for blast furnaces,

[1] Belden, A. W., "Metallurgical Coke," Technical Paper 50, U. S. Bureau of Mines, 1913, p. 41.

because of the Mississippi River and the low freight rates, that it would be an ideal place for the manufacture of iron and steel. I wondered if the experiments with Illinois coke have proven successful.

Mr. Fieldner: One of the samples tested in this research was coke from East St. Louis made from Illinois coal. This coke has been used successfully in a blast furnace at East St. Louis.

It is possible that a little good coking coal was mixed with the Illinois coal in making some of the coke used at the blast furnace.

The East St. Louis coke used in our tests was soft and porous. It would be considered a poor blast furnace coke judged by the usual standards, yet excellent operating records were made in using it.

President Howard: Does the mechanical condition of the ore have a very pronounced effect?

Mr. Fieldner: The mechanical condition of both the coke and the ore has a substantial influence on the operation of a blast furnace. The furnace superintendent must work out the best method of operation for the kind of raw material that he has to charge.

President Howard: Are there further questions or discussion?

THE RELATION OF THE CHEMICAL WORK OF THE BUREAU OF MINES TO CHEMICAL ENGINEERING [1]

By S. C. LIND [2]

Read at the Washington Meeting, December 5, 1923

The chemical work of the Bureau of Mines necessarily touches a very broad field, the greater part of which is either directly or indirectly concerned with the industrial application or uses of chemistry closely related to chemical engineering.

The chemistry of fuels, including petroleum, and of the metallurgy of the common metals will be dealt with in other papers presented at this meeting. The chemistry involved in the nonmetallic, ceramic, rare metallic, and rare gas work of the Bureau of Mines belongs, under its present organization, to the Division of Mineral Technology.

No branch of chemical industry at the present time appears to deserve more attention from chemical engineers than that of the nonmetallics. Many of the nonmetallic industries have attained a high degree of commercial development, represent large financial investments, and produce annually a vast tonnage of raw materials and finished products. Many of these industries are old, much older than most of the metallic industries. The art of ceramics, for example, is as old as the known record of man, and, in many instances, has been the means of the preservation of the earliest records. Naturally, these old industries are not only conservative, but have inherited empirical methods of operation, most of which are now inefficient and out of date. Revising or supplanting these methods is in large part the work of the chemical engineer. The lines of attack are numerous.

For some products higher grades of material (clays, for example) are being used than is necessary for a given purpose. In other cases materials are not being used which could be rendered available by the

[1] Published with the permission of the Director of the Bureau of Mines, Department of the Interior.

[2] Chief Chemist and Chief Mineral Technologist, Bureau of Mines, Department of the Interior.

researches of chemical engineers. Industry is continually calling for more resistant refractories, for higher grades of products capable of meeting more drastic requirements chemically, mechanically, and electrically. They can be furnished only through the researches of the chemists and the chemical engineers.

Many of the problems presented by the rare or uncommon metals and earths are just the reverse of those met in the nonmetallic industries. Instead of an abundant raw material of relatively low value, the market for which is dependent on the location with reference to transportation, we have a raw material which is not abundant, in some cases is extremely rare, which is limited only in a secondary way by transportation facilities or location, and which will stand production under higher costs and on a much smaller scale. Nevertheless, the services of the chemist and chemical engineer are again invaluable in designing the processes and erecting the plants for the treatment of these raw materials, and in their manufacture into the ultimate products.

The rare gases, although noncumbustible and having no interest as a fuel, have, through this very property of inertness, attained practical interest. They furnish the most inert atmospheres which we can command, and are beginning to assume a commercial importance not thought of a few years ago. The helium work of the Bureau of Mines which was initiated by Dr. R. B. Moore, formerly Chief Chemist, is a fitting example of a new industry which should be of the greatest interest to chemical engineers not only for its own sake, but for the bearing it has on the possibility of applications of still broader character.

Since part of your program here includes a visit to the Cryogenic Laboratory of the Bureau of Mines, it may be of interest to consider its work in some detail. During the World War, Professor Cady, of the University of Kansas, discovered that helium exists in certain natural gas of the middle southwest to an extent of 0.5 to 2 per cent. A survey by the U. S. Geological Survey and the Bureau of Mines has shown that we have a great and most unusual resource in these natural gases from which helium can be recovered. It has been estimated that fifty to one hundred million cubic feet of pure helium could be commercially extracted annually in the United States as a by-product of the natural gas industry. The process of extraction is

one of compression and refrigeration by expansion which liquefies all of the constituents (mainly nitrogen, methane, ethane, and higher hydrocarbons) except helium, which is removed at a purity of more than 90 per cent. The liquefied natural gas is then allowed to evaporate, and is returned to the gas mains for distribution. There are many problems in conservation, storage, utilization, methods, and cost of production which can not be discussed at this time. The Army and Navy have cooperated with the Bureau of Mines in the development of helium for use in lighter-than-air craft. A plant is now being operated by the Navy at Fort Worth, Texas, which is producing helium on a commercial scale. The feasibility of its use has recently been demonstrated by the ZR–1. The present cost of production of helium is about ten cents per cubic foot. The Bureau of Mines is making a study to improve methods, which it is hoped will result in materially lowering this cost. At present a semi-commercial plant is being operated at Fort Worth under the direction of the Board of Helium Engineers [3] consultant to the Bureau of Mines. Every hope is entertained of being able to effect a substantial reduction in the cost of producing helium by increasing the efficiency of the process.

The separation of helium from liquid nitrogen, methane, and other hydrocarbons necessitates a knowledge of physical data as to the composition of the coexisting gas and liquid phases, the vapor pressures, specific heats, solubilities, etc., much of which was non-existent at the beginning of the helium work. The Cryogenic Laboratory was installed in the Interior Building in order to carry on the experiments at low temperatures and high pressures necessary to furnish these fundamental data.

The method of separating gases by compression and refrigeration, which is purely mechanical, appears in many instances to have advantages over all other methods. It is already well known as applied in the separation of oxygen from air, and will probably be found to have many other industrial applications. It is expected later to extend the researches of the Cryogenic Laboratory to obtain data applying to other mixtures of gases, the separation of which appears to have industrial interest.

The repurification of helium, which through use has become contaminated with air, presents a somewhat different problem. A repuri-

[3] This Board consists of M. H. Roberts, Chairman; R. C. Tolman; Wm. L. DeBaufre; Edgar Buckingham.

fication plant is now being constructed for the Navy at Lakehurst, N. J. The repurification of helium may also be accomplished by an entirely different method. When active charcoal is cooled to about the temperature of liquid air, its adsorptive power towards all gases except helium (and hydrogen) are greatly enhanced, and very pure helium may be drawn from such a system. This method of repurification is now being applied in a portable installation at present being constructed for the use of the Army at the Navy Yard in Washington under the supervision of the Bureau of Mines.

For further details in regard to the helium activities of the Bureau of Mines, you are referred to a recent address of Dr. R. B. Moore before the Institute of Mining and Metallurgical Engineers, at its Montreal Meeting in August, entitled "Helium—A National Asset."[4]

One problem which seems to be common to the Institute of Chemical Engineers and the Bureau of Mines is the decision as to the proper relation between research and its industrial application. Both of our organizations have practical objects which are largely industrial. Nevertheless both have realized the importance of research of fundamental character, and of the dependence of applied science on purely scientific investigations.

I believe it has been thoroughly demonstrated in the development of chemical engineering in the United States during the past decade that the profession is not only keenly alive to the desirability of research, but that it is ready and able to accept, assimilate, and apply everything of value that pure science has to offer. As representatives of the chemical engineering profession you are to be congratulated on this achievement, which in itself is no small one. This source of gratification, however, should not prevent the realization that it is necessary to maintain a firm balance between fundamental research and the application of its results. The wisdom of stimulating and financially supporting the former has been demonstrated beyond controversy, and I believe is generally accepted by the American Institute of Chemical Engineers.

The Bureau of Mines feels that it can present a record in striving to maintain a proper balance between chemistry and chemical engineering, and to apply their principles industrially, which will meet with your approbation. Only with the cooperation of an organiza-

[4] Transactions A. I. M. M. E. *69*, 110 (1923).

tion, such as the American Institute of Chemical Engineers, does the Bureau of Mines hope to be able to continue its program of development, which is so closely related to your profession.

Discussion

Dr. John C. Olsen: I should like to ask if it is perfectly feasible to take these gases and recover the helium as by-product, and make use of the gases for industrial purposes? Is there any reason why that could not be operated successfully?

Dr. Lind: That is the method being employed.

Dr. Olsen: And the users of the methane would get as good results?

Dr. Lind: It is about the same.

Dr. Olsen: The production of the helium would cover the cost of the treatment, wouldn't it?

Dr. Lind: The helium must be put at a price which will cover the cost. The present cost of production is about 10 cents per cubic foot.

Dr. Olsen: Is there any commercial market for helium?

Dr. Lind: There would be, but all the helium produced so far has been for the use of the Army and Navy, and none has been available to others. But all of the legislation prepared in the past and under preparation now provides for the situation that, eventually, if the needs of the Army and Navy are ever exceeded, they will be authorized to let the industries have such additional amount of helium as will be left over when their needs are taken care of.

Dr. Olsen: You said that 90 per cent helium is used in these airships. What is the other 10 per cent?

Dr. Lind: Usually nitrogen. Just as high purity is desirable as possible. The lifting power drops about 4 per cent for about every 1 per cent drop in purity. We have a new plant at Fort Worth designed by our Board of Consulting Engineers, a small experimental plant which has been put into successful operation, and we hope that the new process will lower the cost of helium from 10 cents to 4 cents, and we hope that the purity of the helium will be increased to as much as 97 per cent. The present production plant has been purifying its product in two steps, first 70 per cent, and then repurifying it and bringing it up to about 95 per cent. The only process

which gives hope of 100 per cent purity is the new process which we are now operating on a very small scale depending on a different principle, the adsorption of gaseous impurities by active charcoal at liquid air temperature.

This is for repurification purposes and not for initial production, but could, of course, be added on for repurification at the top of a purification plant. By "repurification" I refer to helium taken back from the bag, where it has been contaminated by diffusion, with the introduction of about 30 per cent of air; one can not go above that and have any lifting power left. That mixture would be repurified by the adsorption of nitrogen and oxygen in activated charcoal. The method gives very high purity gas, and it may be necessary in the future to add such charcoal units to an ordinary helium plant.

Dr. Olsen: Can't you use some hydrogen?

Dr. Lind: That is a moot question.

Dr. Olsen: I should like your opinion on it.

Dr. Lind: I don't know. That has been proposed. The great difficulty about it is that in repurification, if you do that, you will have a mixture of hydrogen-oxygen, and you will probably have to remove one or both before you use a compression process. If you try to compress without removing one or both of them, I don't want to be around the plant at that time.

Dr. Olsen: But so far as purity of the helium is concerned, that would be a better mixture?

Dr. Lind: It would have more lifting power, but there would be danger in the hangars. At the present time, as a matter of fact, they run oxy-acetylene torches right in the hangars. Accidents already have occurred which would have been serious if hydrogen had been used, but the helium produced no serious results. At ordinary pressure you can go up to about 15 per cent of hydrogen. But when you begin to compress it is a different matter. One of the most serious problems in regard to the operation of these lighter-than-air cars is the fact that the ZR–1 (the "Shenandoah") must take long trips, like the St. Louis one, and must carry a large amount of gasoline fuel, which is burned up, thus lightening the ship all the time. When they want to land the only way they can get down is to valve out some helium, which entails a large and serious loss of gas. The only way proposed to overcome this difficulty is to condense water from

the engine exhaust in a suitable condenser. If you can retain 90 per cent of the water, it would keep the weight equal to the gasoline weight. That has not been done up to the present time. It is a technical problem which will interest you all, but it must be done before helium flying will be successful, unless one adopts the plan of using helium in a separate container and valving hydrogen from other ones to come down. What they do now is to nose down, coming as near the earth as they can, where about 300 marines are stationed to seize ropes to pull them down and anchor them securely.

In St. Louis they had no helium storage, and had no way to replace the helium, so that they had to "land light" in order to get up again.

Dr. R. B. Moore: I want to emphasize that this country has the only large supply of helium gas in the world. We have a unique advantage there not only for war purposes but for other purposes. We could in time of war fill 200 airships like the "Shenandoah." If you stop and think what that means, you will agree with me that the efforts of the Bureau have been justified. In a few years we shall have airships of 5,000,000 feet, and an airship of that kind will be able to go clear across the earth without stopping, and carry a good big tonnage in bombs without stopping.

This country has a weapon of warfare that no other nation has. Therefore I think that the efforts of the Government in conserving this gas for the Army and Navy are worth while. In other words, we want to know that 25 years from now all of this gas will not be gone, and that at some place in the country the Army and Navy will have a reserve. That will not interfere with industry at all. There is enough gas in this country to take care of any reasonable program of commercial development, and at the same time have one field at least where the Army and Navy may have gas preserved in the ground under proper conditions, so that 25 years from now it will be possible to have it.

Dr. Olsen: About that 200 ships—does that mean if they kept it?

Dr. Moore: No. We will know where the helium is. If we have 10 plants similar to the one we have now, we could keep way ahead of any construction of airships.

Dr. Olsen: Then you could keep 200 ships operating?

Dr. Moore: Yes, if we actually have the ships. And you have plenty of helium to keep 200 ships for about 5 or 6 years at least.

President Howard: Let me ask Mr. Lind if that difficulty of reducing the weight could not be overcome by taking aboard a supply of water, by a hose extending to a body of water beneath, taking in water en route?

Dr. Lind: I don't pretend to know anything about the flying operations, but I believe that possibilities of that kind have been thoroughly canvassed. I see people here who know more than I do about it. Probably Dr. Moore could tell you.

Dr. Moore: The great problem now is the conservation of helium gas. At present it is necessary to valve in order to get down. On one of these big airships the loss by diffusion ought not to be more than 25 per cent per annum, but the loss by valving might be more than that very quickly. One of the small blimps ran for two months, and the actual loss on that was only 36 per cent per annum by diffusion. On the big ships it is much less, and should not be more than 25 per cent.

A Member: Is it possible to recover the gas?

Dr. Moore: The question is whether it would be possible to compress the gas from one compartment to another. The compartments consist of very thin silk, from one part to another, and they will not stand the compression. The question of compression of gas into cylinders has been considered, but the weight of cylinders is altogether too much to be practicable.

Mr. Howe: I should like to ask what is your theory as to the origin of that helium?

Dr. Lind: That is a very uncertain thing. Originally it was thought to be from radioactive decomposition, but as we know more about how much helium there is in the earth, it becomes harder to explain it on radioactive theories. But I notice that Professor Rutherford has recently expressed the view that it is probably of radioactive origin. How it happens to be collected in this way is as strange as the history of the collection of other natural gases in the earth.

President Howard: Has it been examined for radioactive indications?

Dr. Lind: Yes; with negative result. You would not expect it. The radioactivity gases are too short-lived to persist in the gas.

President Howard: Is there evidence of radioactivity in the wells drilled?

Dr. Lind: No; no different from other formations in the earth's surface. It is a very small quantity, but in the aggregate so large that it is very embarrassing to the geologists. It means that the total heat evolution is such that the earth must be warming up instead of cooling down, which threatens their whole theory of folding [laughter].

President Howard: You were speaking in the first part of your paper about the rare metals and the likelihood of their being displaced by the reduced demand for them. Would you consider molybdenum as a rare metal?

Dr. Lind: Yes; that is a rare metal. It was used to some extent in the war. I don't believe that the world's use of it exceeded 300 or 400 tons a year in the height of the war. At the end of the war there were such accumulated stocks that they have not yet been used up, and molybdenum steel early showed very unfortunate results in regard to cracks, and it was blamed on molybdenum. At our station at Ithaca new experiments have been made; it is stated by Dr. Gillett that if we have clean steel free from foreign inclusions, molybdenum steel will be of great value.

President Howard: Are there any further questions?

Dr. G. O. Smith: I should like to ask Dr. Lind what might be expected if, for the benefit of the government, a given field is sealed off by some form of governmental action, and the field around about is exhausted possibly, say, to supply gas for illuminating purposes or burning. What would happen to the helium? Would there be changes in the helium content?

Dr. Lind: Do you mean by being drawn away as oil wells are, by tapping it at another point, or by diffusion which would change the relative content?

Dr. Smith: Yes; the latter.

Dr. Lind: I am afraid I am not enough of a geologist to answer that at present.

Dr. Smith: I don't know whether your investigation has covered that or not.

Dr. Moore: If the field is retained by the Government, the Government would have to control the whole of it. Otherwise it would be of no value.

Dr. Smith: There will be a problem in controlling that territory so that the supply will be assured.

Dr. Moore: Yes, sir; surely.

President Howard: Any further discussion? If not, I will declare this closed and we will proceed to the next paper.

TESTING EXPLOSIVES FOR GOVERNMENTAL AND COMMERCIAL PURPOSES[1]

By J. W. PAUL[2] and J. E. CRAWSHAW[3]

Read at the Washington Meeting, December 5, 1923

Since its organization, the Bureau of Mines has engaged in the testing of explosives to promote increased safety, efficiency, and economy in the handling and use thereof. Brought into existence because of several large coal-mine disasters, the Bureau first engaged in the investigation of explosives which could be used with greater safety in gaseous and dusty coal mines. Later, the scope of the work was so widened that the investigations have not been such as to confine the work solely to actual physical tests of explosives, but have included problems in the practical application thereof, and the investigation of the causes of explosions (other than coal-mine explosions) involving the use of explosives.

The diversity of the Bureau's activities in the testing of explosives is shown by the following general headings, under which most of the explosives investigations can be grouped:

1. Permissibility tests
2. Suitability tests
3. Tests of blasting supplies
4. Liquid oxygen explosives
5. Military explosives
6. Utilization of surplus military explosives
7. Ammonium nitrate
8. Tests in the practical application of explosives
9. Investigation of explosions in the use of explosives

At its Explosives Experiment Station, Bruceton, Pa., the Bureau has one of the most complete explosives physical laboratories in existence, and is probably equipped to carry out a greater variety of

[1] Published by permission of the Director, U. S. Bureau of Mines.

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tests than any other single laboratory. Part of the apparatus and equipment in use there was copied from other laboratories established earlier. New apparatus and methods of testing had to be developed to meet the special requirements of the mining industry in this country, and keep pace with the development of the explosives industry.

Most of this apparatus is described in Bulletins No. 15, "Investigations of Explosives Used in Coal Mine," by Clarence Hall, W. O. Snelling, and S. P. Howell, and No. 66, "Tests of Permissible Explosives," by Clarence Hall and Spencer P. Howell. The methods of making the tests are described in Technical Paper No. 186, "Methods for Routine Work in the Explosive Physical Laboratories of the Bureau of Mines," by Spencer P. Howell and J. E. Tiffany.

1. Permissibility Tests

Tests of explosives to determine their permissibility for use in gaseous and dusty coal mines have been, and still are, a very important investigation. This constitutes the largest individual investigation and has precedence over all others. Such explosives must pass certain safety and efficiency tests prescribed by the Bureau before they are admitted to its list of permissible explosives. In the further interest of safety, conditions of use of such explosives after passing the tests are prescribed by the Bureau.

The important safety tests to which an explosive is subjected and which each explosive must pass are the gallery tests, pendulum friction test, and products of detonation.

The gallery tests essentially simulate severe conditions under which the explosive may be used in coal mines where an explosive mixture of gas, or gas and dust with air, is present.

The friction test determines whether the explosive is unduly sensitive to the shocks and friction to which it will be subjected during the normal conditions of handling and use.

A permissible explosive must not evolve on detonation a quantity of poisonous gases which will be dangerous to the miner returning to his working place after a blast. Practical tests have shown that this limit is 158 liters (5½ cu. ft.) per 1½ pound of explosive. Accordingly, no explosive is admitted to the Bureau's permissible list which on detonation evolves more than this limit.

The efficiency tests include the determination of the strength as

shown by its unit deflective charge (determined by the ballistic pendulum), and the rate of detonation (determined by the Mettegang recorded). Experience has shown that the unit-deflective charge must be limited for a permissible to be efficient and still be used under the prescribed conditions. The rate of detonation does not require any limitation other than that the explosive shall always detonate completely.

In order that the users of this type of explosives may be fully informed on this subject, the Bureau frequently issues a complete list of the explosives which have passed the tests, giving the important physical characteristics of each of these explosives. On July 1, 1923, this list contained the brand names of 158 explosives, 23 having been added during the year previous.

In order to maintain the high standard for permissible explosives, the Bureau from time to time re-examines samples of permissible explosives obtained from the magazines of the users, in order to determine how closely they conform to the samples upon which the permissibility tests were originally made, and both the manufacturer and user are notified of the results of the tests.

2. Suitability Tests

With explosives intended for use in metal mines, tunnels, quarries, and other engineering operations, great emphasis must be placed on the efficiency tests, as these explosives are chosen on the basis of their suitability for a particular kind of work. At the same time, the safety tests must not be neglected.

The safety tests consist of friction tests, products of detonation, water-resistance tests, and fire-resistance tests. With the use of this type of explosive the problem of poisonous gases is quite different from that from the use of permissible explosives. Where the workings are underground the ventilation is usually not as good as in coal mines and, in addition, larger quantities of the explosive are fired at a single blast. Hence, it is essential to know both the volume and kind of gases evolved by a unit weight of the explosive, so that dangerous quantities of poisonous gases may be avoided.

Where an explosive is liable to be used under conditions more or less wet, it is important to know the resistance of that explosive to wet conditions in order to avoid misfires due to the explosive being rendered insensitive to detonation through absorption of water.

The resistance of an explosive to fire is important where an explosive is used after "springing shots" and in most open workings.

The efficient use of this type of explosives requires that the strength characteristics be suited for the particular work which it has to perform. These strength characteristics are determined by the unit deflective charge, rate of detonation, compression of small lead block, and theoretical maximum pressure in own volume.

3. Tests of Blasting Supplies

In order that the explosives may be used with safety and efficiency, the blasting or accessory supplies must also be of a high standard and be safe and efficient in use. The most important blasting supplies are detonators, electric detonators, and safety fuse.

The tests carried out on blasting supplies are such as to determine whether they possess the characteristics necessary for safe and efficient use. The most important characteristics are enumerated below.

Detonators and electric detonators are used to initiate detonation in the explosive charge. It is essential that they have a sufficiently large charge and initiating power always to detonate completely the explosive in which they are embedded. Electric detonators should also be waterproof to resist the moisture in wet holes.

Safety fuse should burn at the uniform designed rate and should be resistant to water and should not side spit.

4. Liquid-Oxygen Explosives

Liquid-oxygen explosives (now termed "L. O. X.") are a comparatively recent development in the explosives art. While they were first tried as early as 1899 in the Simplon Tunnel, their use on an extensive scale did not take place until during the World War, when the necessity of using every means of conserving materials for the manufacture of military explosives, especially such materials as nitrates and other oxidizing agents, brought about a rapid development of this new explosive.

While liquid-oxygen explosives were introduced during an emergency, the development has shown that they can compete with the other explosives both in efficiency and cost, in some engineering and mining operations.

In 1917 the Bureau realized that users of explosives should be fully informed as to the availability and practicability of liquid-oxygen explosives and, accordingly, began its investigation and is still continuing the work.

In this type of explosive, liquid oxygen is used as the oxidizing agent when admixed or absorbed by carbonaceous or other combustible materials, with or without some inert absorbent for the liquid oxygen. This absorption takes place immediately before insertion in the borehole or drillhole.

The liquid oxygen is the most expensive ingredient in these explosives, and evaporates readily. The carrying containers and cartridge dipping containers have already been developed to a high degree of efficiency by manufacturers of apparatus for producing and handling liquid oxygen, so that it can be stored and transported without great losses.

Accordingly, the important phases for the further introduction of liquid-oxygen explosives are the development of the absorbent materials and the technique of the blasting operations. The Bureau is at present engaged in an investigation of the physical and chemical properties of absorbents in cartridge form to determine what properties are required for the most suitable absorbing material. At the same time, practical tests in the field are being made to develop the best methods of manipulation in blasting.

The investigation also includes the study of the effect of liquid oxygen on the accessories which are used during the blasting operations.

5. Military Explosives

During the World War, the Bureau of Mines, at the request of the War Department, undertook the determination of the physical and chemical characteristics of practically all the military high explosives then in use or proposed for use. This investigation has continued until very recently.

Each explosive was subject to complete tests to determine its fitness for the purpose for which it was used or proposed to be used.

Those explosives proposed for use as bursting charges were tested under the conditions of density and confinement simulating those actually met with in service. Those for demolition purposes were given tests applicable to this service, while all explosives were

subject to severe sensitiveness tests, friction, impact, and bullet penetration.

As a result of this work the basic characteristics have been determined on a large number of the important military explosives and important data previously unknown have been made available.

6. Utilization of Surplus Military Explosives

At the close of the World War the Government had on hand large stocks of military explosives, the storage of which entailed a large expense. The Bureau, therefore, undertook investigations of the possible utilization of the surplus stocks of TNT, Trojan grenade powder, picric acid, and smokeless powder as industrial explosives. These investigations showed that these explosives could be economically used and, as a result, large quantities of military explosives were allotted by the War Department to other departments of the Government. The larger part of these allotments have been used in general blasting, such as land clearing, ditch digging, road building, and a variety of other projects, with economical and satisfactory results. It is doubtful whether this method of salvaging these surplus stocks would have been deemed advisable had it not been for the investigations of the Bureau. In addition to making the routine chemical and physical tests, practical field tests in breaking boulders, removing stumps, etc., were carried out before recommending their use for general industrial blasting.

7. Ammonium Nitrate

Ammonium nitrate ranks next to nitroglycerin in importance as an ingredient of industrial explosives, and is used in very large quantities. It is estimated that approximately 50,000,000 pounds was used as an ingredient of explosives during the year 1921. It is also largely used in the manufacture of fertilizers.

While it is of itself an explosive, it can be made to detonate only with difficulty, requiring powerful initiators. Yet a number of disastrous explosions of ammonium nitrate have occurred during its manufacture and storage, notable among which are those at Oppau, Germany; Repauno Plant of the E. I. duPont de Nemours & Company, Gibbstown, N. J., and the Morgan, N. J. fire and explosion.

The investigation being carried out by the Bureau has as its ob-

ject the determination of the conditions under which it will detonate and the fundamental conditions contributing to an increase in the hazards during manufacture and storage.

8. Tests in the Practical Application of Explosives

A thorough technical investigation of the methods of mining in many mining and engineering operations would often result in the obtaining of more efficient and economical results from the explosives used. Such investigations should require the correlation of laboratory tests with the field results for their most satisfactory solution.

The Bureau has from time to time conferred with users of explosives with the view to aiding them in the solution of their blasting problems, and has in many cases co-operated with them in carrying out tests.

Occasionally, an important problem in the practical application of explosives can be solved in the physical laboratory alone. Such a case was the determination of the effect of cartridge diameter on the strength and sensitiveness of certain high explosives extensively used in metal mines, where it was shown that the use of smaller diameter cartridges than 1¼ inches decreased the explosive efficiency and sensitiveness of the explosives. The efficiency thus lost is an important factor in the mining costs, while the decrease in sensitiveness might cause a greater number of accidents, greater loss of shots (misfires), and increased production of poisonous gases.

In the mining of coal, in many fields the percentage of lump coal has a very important economical and commercial bearing. An investigation is now under way studying the means of increasing the production of lump coal by improved blasting methods, which it is hoped will show the fundamental conditions entering into a solution of the problem.

9. Investigation of Explosions in the Use of Explosives

Any program to increase safety in the use and handling of explosives would be incomplete unless such program included the investigations of the circumstances surrounding accidents in the field involving the use of explosives. The Bureau's explosives engineers, where practicable, promptly proceed to the scene of such explosions and study first-hand the conditions surrounding any accident.

The Bureau's representative does not, under any condition, try to fix the responsibility for the accident, but merely the conditions contributing to the accident. Samples of the explosive and blasting supplies in use at that time are often procured and forwarded to the Explosives Experiment Station for safety tests.

On completion of all phases of the investigation, a report is prepared detailing the particulars of the accident, the evidence procured, tests carried out, and the practices in use at the particular mine or quarry, etc.

If the facts warrant, conclusions are shown setting forth the cause of the accident, and recommendations are made to prevent a future similar recurrence. At the same time, attention is drawn to other unsafe practices that may not have contributed to the accident, but which may be the cause of other accidents. Where safety practices of merit are observed, special attention is drawn to such practices.

These investigations in many cases have been of much value to the user of explosives, and have furnished the information necessary to recommend precautionary measures, of value to all users of explosives.

Discussion

Dr. Chas. E. Munroe: Mr. President, I found on my desk a copy of this paper together with a request that I appear here to make remarks upon it. I presume I am invited to do so because I have been connected with the Bureau of Mines since it was organized, and with the antecedent Technologic Branch of the U. S. Geological Survey carrying on this work, and may be presumed to have kept in touch with the activities of these organizations throughout this time.

After reading the paper I may say I endorse all that the writers have said. They refer to several valuable publications issued from the Pittsburgh Testing Station. Attention may well be called also to "The Effect of Cartridge Diameter on the Strength and Sensitiveness of Certain High Explosives," by S. P. Howell and J. E. Crawshaw, and "The Effect of Stemming on the Efficiency of Explosives," by W. O. Snelling and Clarence Hall, as being two among the many publications of this Division, which have proved to be of great importance.

I notice that the authors have referred to the chemical work of

the Station in which you as chemical engineers would be most interested. Naturally, with the beginning of the Pittsburgh Testing Station, a chemical division was created in that establishment, and the office of the Chief Chemist has been filled by Dr. Snelling, Dr. Storm, Mr. Cope, Dr. Huff, and Mr. Taylor; all excellent chemists and all having rendered most valuable service. From the beginning it was agreed that in the testing of explosives it was essential we should first know what compositions were being tested. Every sample was to be analyzed at the outset of the testing. At the time work began methods for analyzing explosives were not well worked out, and this became one of the problems of the explosives chemical laboratory at Pittsburgh. From that day to the present much attention has been given this, and many publications relative to the methods of analysis have been sent forth showing the methods used by the Bureau of Mines. Publications in this field have been deemed essential in order that the manufacturers and consumers of these explosives would know how the analyses were made, so that if any issue should arise they might apply the same methods in their examination of the materials. I believe that a great deal of most excellent work has been done in that direction. Among their publications special attention may be called to "The Analysis of Black Powder and Dynamite," by Snelling and Storm; "The Analysis of Permissible Explosives," by Storm; "Analysis of Detonating and Priming Mixtures," by Taylor and Rinkenbach; and the recently issued "Explosives: Their Materials, Constitution and Analysis," by Taylor and Rinkenbach.

The Bureau has recognized that in order to promote analytical work, and to get the best knowledge of explosives, it is essential that we should know as fully as possible the characteristics of the constituents of such explosives. Hence their constants, such as melting points, densities, solubilities, etc., must be determined. Were you to examine the literature of explosives you would find very few of these set forth, even in foreign publications. We chemists know that by these means we are provided with additional facilities by which to separate the components of mixtures and to develop analytical methods. In the chemical laboratory they are now determining the solubilities for a wide variety of solvents. This is a part of the work that is going on there and a great deal of additional work on these lines is now planned to be done.

Another matter to be spoken of is the policy adopted by the first

Director of the Bureau of Mines, Dr. Holmes, and which has ever since been followed. If you recall the peculiar organization under which we live, a Federation of States accepting a Constitution under which the states retain much of their sovereign powers, and especially the police powers, it becomes apparent that though the National Government, represented in this case by the Bureau of Mines, may discover means and formulate regulations by which to increase economy and efficiency and promote safety in the use of explosives, it has no means of enforcing these regulations within the States, thus differing from many other Governments, such as those of Europe. It was also recognized that there exists perhaps more powerful forces than laws or regulations, and these are "public opinion" and "the best practise." You, as chemical engineers, are best qualified to appreciate what these mean, especially the last, for in case an accident occurs and one is drawn into the courts the result of the issue is frequently determined by whether or not the "best practise" has been followed.

Relying upon these forces has brought results which could hardly have been expected, but which are clearly shown in the statistics of production and consumption of explosives, which have been collated by Messrs. Fay and Adams, who have, successively, filled the position of statistician of the Bureau of Mines.

Another policy adopted by Dr. Holmes was that of taking all concerned into his confidence. When the apparatus was being installed at the Pittsburgh Testing Station, he sought the counsel of all interested. He even invited foreign experts from Germany, France, Belgium, and England, where similar investigations were being carried on, to visit the station and give the Bureau the benefit of their experience. Also, before attempting to fix any conditions for conducting the tests, or formulating the conditions a "Permissible Explosive" must satisfy, he called into conference representatives of all the manufacturers of explosives and of the users of explosives, at which the matter was fully discussed.

At the beginning, it was not known how exact our methods, or how precise our results might be. We had to modify, as our methods of testing continued. Hence, after some years, when we had accumulated many data and the matter came up of re-examining samples of explosives secured from the field, for the purpose of checking "permissible explosives" in use, before the limits of tolerants were fixed, another conference of manufacturers and users was assembled and

the data fully discussed, and the limits fixed. Again, when the Bureau, during the war, was charged with the enforcement of that law known as Explosive Regulations, all those who were to be affected by this law were assembled and their advice sought before the regulations, under which that Act was to be enforced, were put into operation. I believe that much of the success which the Bureau has achieved is due to the policy outlined above, which it has consistently followed. [Applause.]

PRESIDENT HOWARD: Is there further discussion?

JEROME ALEXANDER: I should like to ask Dr. Munroe if anything has been done relative to the influence that the physical state of the explosive has upon its power and sensitiveness. I have in mind some work done by Lowndes of England * on the sensitiveness of lead azide, which is reduced by protective colloids.

DR. MUNROE: There was a very extended investigation of that carried out in Australia. Some work of that kind has been done at the Bureau of Mines and experiments are being continued, but no publications have been made further than incidentally in the papers. There have been no complete investigations other than that one in Australia which was quite exhaustive.

PRESIDENT HOWARD: Is there further discussion? If not we will call this closed.

* "The Physics and Chemistry of Colloids," page 128, London, 1921. Joint Meeting of Faraday Society and Physical Society of London.

THE FUELS WORK OF THE BUREAU OF MINES[1]

By O. P. HOOD[2]

Read at the Washington Meeting, December 5, 1923

When, in the study of the geology of the country, its ores, minerals, fuels, and other useful materials are considered, the methods of reducing them to possession and putting them into useful form are a natural extension of inquiry. A technologic branch of the Geological Survey had interested itself in such problems, especially in a study of fuels, and this formed the basis of the work afterwards separated from the Survey and developed into the Bureau of Mines. The national accent on conservation coincided with this special study. There was a demand for a knowledge of the character as well as of the extent of our fuel resources, and for direction as to the best use that could be made of them. The Organic Act establishing the Bureau of Mines, as revised in 1910, therefore, contained these words, "That it shall be the province and duty of the Bureau of Mines to conduct inquiries and scientific and technologic investigations concerning mining and the preparation, treatment and utilization of mineral substances," etc., fuel being one. At the time of this revision an extensive program of coal sampling and analysis had been started, and Government purchases of coal were made on a quality basis requiring much local work of this sort. This was not primarily investigative work, but rather an administrative detail relating to efficient purchase and use, and to assure authorization for such work a further specific reference to fuel was added. This reads, "and on behalf of the Government to investigate the mineral fuels belonging to or for the use of the United States with a view to their most efficient mining, preparation, treatment and use." The Bureau was further directed "to disseminate information concerning these subjects in such manner as will best carry out the purposes of the Act," which purposes were "improving health conditions and increasing safety, effi-

[1] Presented by permission of the Director, Bureau of Mines, Department of the Interior.

[2] Chief Mechanical Engineer, Bureau of Mines.

ciency, economic development, and conserving resources through the prevention of waste in the mining, quarrying, metallurgical and other mineral industries."

The Bureau's fuel work is, therefore, broadly investigative as in any mineral field, but also directed towards specific problems of the Government as an owner of fuel lands and as a very large user of fuel in a great variety of plants. The dissemination of this work so that it shall do the most good is no small part of the total duty imposed. It is obvious that with so large a field, and with appropriations naturally restricted, effort must be wisely limited. A multitude of things might be done, each good, but producing little or no lasting effect. Things might be done of limited local interest, and certainly these should not be first considered. There are many things that other agencies can do as well or better, and there should be no haste in such duplication of effort or competition of field. So far as may be, the Bureau should interest itself in those investigations of timely fundamental nature and general applicability that other agencies can not or will not make.

The Bureau might attempt a house to house campaign to teach the householder the proper use of fuel, and no doubt fuel would be saved and some good would be done, but the effect would be temporary, local, and applicable to perhaps one-sixth of the fuel used. However, the results of increasing our knowledge of the combustion process and what goes on in a furnace fire will be continuously applied through generations, and by those designing apparatus using the greater quantity of fuels. Thus, to have an effect on the problem at the sources of fuel use will be far more potent, although perhaps less obvious. These are the thoughts underlying the general direction of the fuels work of the Bureau, and should be borne in mind when making a brief survey of the results. What the Bureau has accomplished to date may, perhaps, be summarized as follows:

There is a general tendency on the part of inquirers to look to the Bureau of Mines for authoritative information concerning all the technical questions that arise in the use of fuels, and to be disappointed if they find their particular interest untouched as yet. This is true not only in regard to scientific facts, but also to current engineering application. A worker in these fields sooner or later depends on the Bureau of Mines for some demonstration, fact, or com-

pilation to sustain or give direction to his own work. This is the position the Bureau seeks to maintain and to be worthy of, for in this way the purposes of the Act are believed to be best attained.

Of the 150 applications that have been issued on fuel studies, 60 of them are largely chemistry, appealing primarily to chemists, while 90 appeal more directly to engineers, although making free use of chemistry as a tool. There has been a great deal of coal analysis. Samples are analyzed for the United States Geological Survey, for their records of coal resources; analyses of coal purchased are made for nearly every Government department and for several states. The laboratory at Pittsburgh has a capacity of about 1,000 samples per month, which in matters of quantity production puts it on a strictly commercial basis. Strictly standard methods are maintained in order that commercial laboratories may check against the results obtained by the Government laboratory. In the conduct of almost any investigation involving fuel, proximate or ultimate analyses are also needed. We desire to know the quality of coal in so far as disclosed by analyses from every mine in the country, although our records are far from complete.

Much has been done on methods of analysis, on the way in which volatile matter, moisture, sulphur, and oxygen occur in coal, and methods of determining the fusibility of ash. Much work has been done on gas analysis to perfect it as a tool for the use of the combustion engineer. The combustion process has been studied in the chemical laboratory and in the boiler furnace. We have been interested in gas producers, foundry cupolas, water gas sets, coke ovens, cook stoves, and the family furnace. Most of the fuels have received some attention—coal, lignite and peat, natural and manufactured gas, tar, petroleum and its distillates.

Fifteen years ago many engineers believed we were on the threshold of a gas age, and that great gas-engine plants were to replace steam boilers and engines. In any such movement there is at first much confusion as to the technical facts and to what extent hope and financial interest in sales of equipment influences current opinion. At such a time the Bureau tries to authenticate basic facts, giving a substantial foundation on which to build. This has been true in regard to the movements involving the gas producer, smokeless combustion, briquetting, powdered coal, and other movements. Since it

has nothing to sell and has a desire only to discover the facts, the Bureau's findings have come to be carefully considered.

The Bureau's main laboratory is at Pittsburgh, and about fifty-one of the people there are paid from the fuels appropriation. Work is also conducted in the field and at other stations. An investigation of lignite that has ranged from Texas to Canada is just drawing to a close, and an investigation of peat as a fuel is just beginning. Field sampling of anthracite coal is being carried on in Massachusetts, and sampling of mines desiring to furnish coal to the Navy is going on in several states. The laboratory car " Holmes " is just returning from a campaign in several states where work at ceramic kilns has been conducted.

In Washington fuel engineers are studying the fuel burning plants of the Government with a view to greater economy in the use of fuel.

I have attempted to give a very brief sketch of the Bureau's fuels works, its general plan and objective, and a few illustrations of its interests, without going into detail which can best be learned by a study of the Bureau's publications.

RESEARCH ON PETROLEUM

By H. H. HILL*

Read at the Washington Meeting, December 5, 1923

The work of the Petroleum Division of the Bureau of Mines is divided into two general classes: research or investigative work and supervisory work on public lands. The administrative office of the Division is maintained at Washington, and field offices or stations are maintained at Bartlesville, Oklahoma; Shreveport, Louisiana; Dallas, Texas; Denver and Boulder, Colorado; Casper and Salt Creek, Wyoming; Winnett, Montana; San Francisco, Bakersfield, and Taft, California. The Petroleum Division also supervises oil and gas operations on certain Indian lands, and in carrying out this work has stationed engineers at a number of different Indian agencies in Oklahoma, New Mexico, and Wyoming.

Under the act of Congress of February 25, 1920, to promote the mining of coal, phosphate, oil, oil shale, gas, and sodium compounds on the public domain, the Secretary of the Interior charged the Bureau of Mines with the supervision of drilling and production on public oil and gas lands. In carrying out this work the Petroleum Division maintains a force of engineers, gagers, accountants, and expert drillers, in order to make certain that operations on Government lands are carried out in an efficient manner and that the Government receives its full share of royalties due. The extent of this supervisory work of the Bureau can be realized when consideration is given to the fact that oil and gas are being produced on Government lands in Wyoming, Montana, Colorado, Utah, Louisiana, and California, and wells are being drilled on Government land in Alaska and in practically all of the western states. The royalties accruing to the Government from oil and gas operations on public lands, even at the present low price of oil, amount to approximately $700,000 monthly, and the total royalties that have accrued to September 1, 1923, have amounted to $15,791,547.69.

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The Petroleum Division of the Bureau of Mines also supervises drilling and production on Naval Reserves 1 and 2 in California, and Naval Reserve No. 3 (Teapot Dome) in Wyoming. To September 1, 1923, the royalties accruing from oil and gas operations on Naval Reserves have amounted to approximately $2,750,000.

The research and investigative work of the Petroleum Division is conducted at the Experiment Station at Bartlesville, Okla., and at the field offices at Dallas and San Francisco. A small amount of investigative work is also carried on at the different leasing offices in connection with the supervisory work on Government lands.

Numerous references have been made to the need for research work in the petroleum industry, and many problems have been suggested as being worthy of consideration. The Bureau of Mines has long recognized the need for work on a number of problems, but due to lack of funds has not been able to assign men to all work that is important. An attempt has been made, however, to conduct work on problems that are of immediate importance to the different branches of the industry.

The petroleum industry may be roughly divided into the following branches: exploration, development, producing, refining, and marketing. Closely associated are the industries of natural gas and natural gas gasoline. The exploration branch selects the structures that are favorable, the development branch drills the wells, the producing branch takes charge of the completed wells and by keeping them in repair maintains a source of oil for the refinery, the refining branch runs the oil through stills and by various methods of distilling, treating, chilling, filtering, etc., separates the crude oil into a number of finished products which are turned over to the marketing branch of the industry. The work of the Bureau of Mines on problems affecting the petroleum industry covers all branches with the exception of exploration and marketing. Work in connection with these branches is handled by other Government departments.

In a short paper of this kind it is impossible to discuss all the problems upon which the Bureau is engaged. A selection has therefore been made of a problem in each branch of the industry, and in choosing the particular problems for discussion an effort has been made to select typical problems that would be of interest to the chemical engineer.

Study of Mud-laden Fluid and Cement

In the drilling of oil wells by the rotary method, mud fluid is used to carry the drill cuttings to the surface and to prevent caving of the walls of the hole. It is also used to prevent the infiltration of water and to confine upper oil and gas deposits to their respective strata in order that the well can be drilled to the deeper oil sands. One of the problems involved in the use of mud fluid is to get a mud that is heavy enough to plaster the walls of the hole effectively and at the same time is of such consistency that it can be readily handled by the pumps. Another problem is to obtain a mud in which the clay particles will remain in suspension for a comparatively long period of time. Engineers at the Bartlesville Station are making a thorough study of mud fluids, both in the laboratory and in the field, in an effort to determine the effect of adding different materials for increasing the weight of mud without appreciably increasing the viscosity. Studies are also being made of the rate and amount of penetration of mud fluid into different formations, and of the effect of adding different chemicals to prevent settling.

The most effective method of shutting off water in oil wells is by the use of cement. It is frequently difficult to get good cementing jobs, however, owing to agitation by gas or water, high concentration of salts in the water, or to the use of a poor grade of cement. A series of tests is now being conducted to determine the effect of water from different wells on the setting properties of cement, and for carrying out this work samples of water are being obtained from wells in all sections of the country. Tests are also being made to determine the effect of pressure on the initial and final set and the effect of high ratios of water on the tensile strength.

Work on Oil Field Emulsions

One of the most important problems in the producing branch of the oil industry is the separation of oil from oil-water emulsions. In a number of fields the oil as it comes from the well is so badly emulsified that it must be treated in some way before it will be accepted by the pipe line company. It has been estimated that during the years of 1920 and 1921 more than 100,000,000 barrels of "cut" oil were produced in the Mid-Continent and Gulf Coast Fields, and of this amount only about one-half was saved. The fields in California also produce large quantities of emulsified oil.

The Bureau of Mines, in studying this problem, is not only collecting information on methods that are being used in the different fields, but is also obtaining fundamental data on the nature of emulsions and the reasons for their formation. It has been found, for example, that oils containing appreciable amounts of asphalt are more likely to form emulsions than those that are practically free from asphalt, and that the presence of finely divided materials is also of considerable importance.

Separation of Wax from Wax Distillate

In the manufacture of lubricating oils from crude oils containing appreciable amounts of paraffin wax it is often extremely difficult to remove the wax by chilling and pressing, with the result that the lubricating oils have high cold tests. It has been found that some crudes yield a wax distillate that can be readily pressed, while that obtained from other crudes clogs up the filters to such an extent that it is practically impossible to obtain a good separation.

In studying this problem the Bureau of Mines has obtained samples of wax distillate from a number of different refineries, and has prepared a number of samples by making use of the experimental refinery at the Bartlesville, Oklahoma, station. Laboratory tests have been made on these samples in an effort to obtain data on methods to be employed in order to obtain a maximum yield of crystalline wax. A number of tests have been made with the experimental refinery using different crudes and accurately controlling the distillation, chilling, and sweating processes.

Transmission Losses of Natural Gas

A study is being made of the leakage of natural gas in transmission lines. The loss by leakage from the gas field to the consumer is frequently quite important, for it not only means a decreased revenue to the company, but also results in a waste of a valuable fuel. Experiments are being conducted to determine the rate of flow of natural gas through small orifices and through leaks of different kinds. The effect of pressure on the rate of leakage is also being studied.

Arrangements have been made for conducting tests on a number of natural gas pipe lines. Experiments will be made on lines of different types of construction, and at widely different pressures, and

an attempt will be made to determine the importance of such factors as age of line, depth and character of covering material, corrosive action of soil, etc.

Methods of Treating Natural Gas Gasoline

An important problem that has been solved by one of the engineers of the Bureau is the treatment of natural gas gasoline to meet the "doctor test." Gasoline frequently contains certain unstable sulphur compounds, and unless these are removed they break down and form products that give the gasoline a yellow color and bad odor. In refineries these sulphur compounds can be removed at comparatively little expense, due to the large quantities of gasoline that are treated, but in small gasoline plants, where the supply of water is limited and expensive equipment is not justified, the problem is of extreme importance.

A simple method of treatment was developed in the laboratory, and was then tried out on a small scale at one of the gasoline plants. The method proved so successful that it was installed by a number of gasoline plants and to-day several thousand gallons of natural gas gasoline is being treated by this method at a cost of only a fraction of a cent per gallon.

Research on Oil Shale

For the past five years the Bureau of Mines has been conducting research work on oil shale in order to be in a position to advise oil shale operators as to the best methods for extracting oil from shale. As the supply of petroleum decreases it is very possible that the country will turn to oil shale as a source of liquid fuels and lubricants, and by studying the fundamentals of the shale industry it is hoped that, by the time the shale oil is needed, satisfactory methods will be developed for retorting the shale and refining the shale oil.

Tests are being made with various kinds of retorts and under different operating conditions for the purpose of determining the method that will give the highest yields of the best oils from the different shales. Various methods of refining are being studied to determine the methods best suited for the different oils. Comparative studies have also been made of methods of retorting and refining that have been successful in the oil shale industry in Scotland. An

exhaustive study is being made of the distribution of nitrogen in the shale, as ammonium sulphate is expected to be an important by-product of the American shale oil industry.

Other important problems that are being studied by the Bureau of Mines are: a thorough study of the properties of crude oils from practically every important producing field in the world, development of standard methods for testing crude oil and petroleum products, methods of reducing evaporation losses, methods of increasing the efficiency of fractionating equipment in use in refineries, methods of reducing the amount of gas necessary for bringing oil into wells, etc.

The amount of research work on petroleum that remains to be done is practically unlimited. It is encouraging to note, however, that the oil industry realizes the importance of such work and practically all the larger companies now maintain a number of research men. As the production of oil decreases research work will become of increasing importance, as it will doubtless be necessary to improve the methods now being employed and to make better use of a number of the products that are now being wasted or are being burned as fuel oil.

Discussion

Dr. J. C. Olsen: I should like to ask what the rotary method of drilling is?

Dr. Lane: As I remarked, this paper was prepared by Mr. Hill, and I very much fear that I shall have to stick to generalities in regard to answering questions, as most of this paper is outside my own field. I can not give you the detailed method of rotary drilling, but I suppose that phrase is used in contrast to the older method in which the motion of the drill was vertical.

Dr. Olsen: What is the method of removing sulphur that you spoke of, a very simple method, in the laboratory?

Dr. Lane: That method involves the treatment with the "doctor" solution and is principally applied in the smaller plants. I can not just tell you the extent of the application of the process but I know it has been very effectively applied to this purpose. It involves treatment with oxide of lead and sodium hydroxide.

Dr. Oscar H. Reinholt: Perhaps I can explain that drilling. The cable system you are familiar with. The rotary system was introduced by Captain Lucas in Beaumont, at Spindle Top, the

greatest oil well ever brought in, north of the Rio Grande, which came in on January 10, 1901. Captain Lucas, in testing for oil, and particularly for silver in Louisiana, on various islands and on the mainland, had used the diamond quartz drill, with which he was evidently familiar in his work in Europe. He found difficulty in getting through the shifting sands of the Gulf Coast. So he applied a modification of the diamond quartz drill which now is known as the "rotary drill," and which consists of a series of hollow rods, with a column of water running down inside to bring up the cuttings on the outside. By that method he got down to a depth of over 1,000 feet, and brought in that well. The drill, then, consists of these tubes, a little heavier than ordinary pipe, rotated from the surface with rotating mechanism, while at the lower end they usually have saw teeth, that cut through the softer formations.

The cable system is better adapted for the firm formations because that, by means of the shock and not the pressure, is able to work its way through the more resistant and springy formations. The rotary system is applicable in the softer and less consolidated formations. The rotary method has proved very successful in the matter of speed, but it has proved a failure on many occasions because of the rapidity of the drilling and the fact that the rotating mechanism brings up some of the original cuttings which go down inside of the pipe. The result has been that many important oil sands have been lost entirely, outside of the Gulf Coast where this has been used. The recent development in California and in a number of other places, too, has been so rapid because of great speed of the rotary drill in certain forms——

President Howard: What is that speed? How many feet an hour?

Dr. Reinholt: I suppose that records have been made of 200 feet in a day, undoubtedly, and with the ordinary diamond quartz records of 50 to 100 feet. The diamond quartz type depends on the question of value. Sometimes a dozen or two dozen diamonds are set in the drills, and it may be that the carbons will run up into $300, $400, or $500. I just wanted to bring out the point of the disadvantage of the ordinary rotary drill, which is a modification of the ordinary diamond drill, because it misses so many things. Its efficiency, so far as speed is concerned, is dangerous and uneconomical so far as actual work is concerned.

Dr. Olsen: The rotating pipe is placed down in the ground in the usual way, is it?

Dr. Reinholt: The machinery holds that, and there is a progressive feed which can be adjusted in accordance with the speed. They are similar to the diamond quartz drill. The diamond quartz drill makes its progress by two methods: one is by hydraulic pressure with ball bearings, and the other is by means of positive gear feed. And it demands a rotary velocity of 150 to 600 per minute. I have taken the trouble to explain this method briefly in a published book that I am getting out as a result of my work with the Treasury Department. There are a number of concerns organized to develop oil fields along those lines.

Dr. Olsen: And sell the stock?

Dr. Reinholt: But I am taking the trouble to explain this briefly in a book that is forthcoming. I don't mean to mention that now, but the public, I think, needs information along those lines, and it is up to us as engineers to help along progressive methods.

Mr. G. W. Thompson: I should like to ask the speaker how many grinding tubes there are in such a rotary drill?

Dr. Reinholt: Four to six generally.

Mr. Thompson: Are there a number of tubes used? I think I understood you that way.

Dr. Reinholt: Not one tube inside another, but in succession, in series, fastened together, very much as in the diamond quartz drill.

Mr. Thompson: Across a given section is there only one tube, or are there more?

Dr. Reinholt: There is a cone now used, and has been used probably for a dozen years, which grinds up the material when it happens to be hard and they don't care to ease the percussion. That is a series of diamond core grinders in a form of a complex cone.

Mr. Thompson: You have not answered the question, but it does not matter.

Dr. Reinholt: It is a modification of the tube.

Mr. Thompson: You spoke of the tube being small.

Dr. Reinholt: There is but one tube.

President Howard: Is there any further discussion?

SOME ASPECTS OF THE APPLICATION OF OXYGEN TO METALLURGICAL AND ALLIED FIELDS

By F. W. DAVIS

Read at the Washington Meeting, December 5, 1923

The efficiency of metallurgical and allied processes has been materially increased of recent years by more careful preparation of the raw materials previous to their use. It has been recognized that the use of a raw material containing an excess amount of inert matter is wasteful in that the inert content will be heated to the temperature of the reaction, decreasing thereby the heat available for useful work. For this reason developments have been made in greatly minimizing the inert content of our ores and fuels, the results of which are from a commercial standpoint quite gratifying. When considering these developments and results, does it not seem strange that while we go to considerable trouble and expense to prepare some of the raw materials, the chief material in terms of tonnage used in any pyrometallurgical process, viz., air, is still used in the very dilute condition as supplied by nature? For every ton of carbon burned by air to carbon monoxide we consume one and one-third tons of oxygen, carrying with it as inert matter nearly four and a half tons of nitrogen.

The matter of using oxygen-enriched air has received much discussion, but very little real progress has been made. Some experiments were conducted in Belgium just previous to the war, but little information has been given of the results; in fact, it is quite possible that owing to the short duration of the test conclusive results were not obtained. The greatest obstacle to developments along this line has been our inability to procure oxygen in large enough quantities and at such a low cost as to permit of its general use. With this in view, and realizing the tremendous importance of such developments to the industry as a whole, the Director of the U. S. Bureau of Mines requested Mr. M. H. Roberts, Chairman of the Board of Helium Engineers, to act as chairman and select an advisory committee to

the Bureau for the solution of this problem. When we consider that the gentlemen selected by Mr. Roberts to study the manufacture of oxygen are all members of the Helium Board of Engineers who have just completed revolutionary developments in the separation of gases, and that these same gentlemen predict that oxygen for metallurgical purposes will be available in the very near future at a cost not to exceed $3.00 a ton, it behooves the chemist and metallurgist to give the subject considerable study, in order that we may be in a position to use this new development to greatest advantage.

The metallurgical group of the advisory committee has made preliminary studies on the effects to be expected with the application of oxygen to ferrous metallurgy. This subject is of such broad scope and promises such revolutionary changes both in process and equipment that it is almost impossible even to approximate conditions to be expected with rich oxygen mixtures. In fact, we feel that we are on the verge of a new metallurgy and one with possibilities never before contemplated.

The iron blast furnace, being the largest single unit in ferrous metallurgy, will probably be the first to benefit by cheap oxygen. In considering the thermal conditions of a blast furnace we must consider the furnace as being divided into two distinct zones: the shaft, or the zone of reduction; and the heart and bosh, the smelting zone. The reduction of iron oxide by carbon monoxide requires comparatively low temperatures, while the smelting must be done at an extremely high temperature, and the heat available for this latter work is effective only when supplied above a certain minimum or critical temperature. The amount of smelting heat available, therefore, will be dependent on two factors: first, the total heat generated; secondly, the thermal capacity at the critical temperature of the materials present. In modern practice we increase the available smelting heat very materially by pre-heating our blast. This increase in heat constitutes only a small portion of the total heat generated, but inasmuch as it does not in any way affect the thermal capacity of the materials present, the increase in smelting heat is quite appreciable. Even with this practice of pre-heating the blast the ratio of available smelting heat to the total heat generated is only from 1 to 4 to 1 to 5. From further analysis of the thermal quantities we learn that the nitrogen of the blast absorbs as sensible heat about 40 per cent of the total heat

generated, or, in other words, that we are actually expending nearly twice as much heat in raising the temperature of nitrogen as for the useful work of smelting.

By decreasing the nitrogen in the blast we will decrease the amount of heat carried into the shaft section, but inasmuch as the shaft heat in present practice is in excess of requirements, we have some margin on which to work without expecting difficulty in this zone. From our study, which has of necessity been too lengthy even to outline here, we have concluded that a blast containing 31 per cent by weight of oxygen can be utilized in the present furnace, and that higher concentrations probably will be used with correspondingly higher economies in different type furnaces. With 31 per cent oxygen we will eliminate all necessity of hot blast stoves, which are not only the most expensive part of the blast furnace equipment, but a constant source of trouble. We will increase our present production by 18 per cent and decrease the total cost by nearly 7 per cent. In addition, we will increase the flexibility of the process by giving the operator direct control over conditions in his smelting zone, we will increase the uniformity of the product, and what is of even greater importance, we will make possible the use of much cheaper raw materials. When we consider that these improvements will be possible when using oxygen enriched blast in equipment designed and constructed for the use of a blast containing 77 per cent inert matter, it becomes extremely difficult even to attempt to predict the economies which will be possible with equipment designed specifically for the use of high oxygen blast.

The Bessemer converter appears to be a field of promise for the introduction of oxygen. In the Bessemer process the greater portion of the necessary heat is developed by the oxidation of metalloids in the molten iron. We pay rather heavily for increasing the silicon content of pig for the acid Bessemer process in order that the quantity of this fuel may be sufficient to supply the thermal requirements. The basic process has been practically abandoned in this country because we do not have iron ore containing sufficient phosphorus to give high phosphorus or basic Bessemer pig iron. On the other hand, we have large tonnages of ore which do contain much more phosphorus than is desirable for open hearth processes. Pig iron made from this ore could, without difficulty, be used in the basic Bessemer

if we had available an oxygen enriched blast, and the added refinements made possible by direct temperature control would probably result in a steel of open hearth quality.

We will probably be unable to utilize the increased calorific intensity possible with oxygen for combustion in our present open hearth. The refractories used in the furnace are at present subjected to thermal conditions very little short of their point of failure. If, however, we can secure refractories which will permit of higher temperatures, we will be enabled to speed up our process materially by the high flame temperatures available with oxygen. The impurities of our bath are, at present, removed by the oxidizing action of iron ore. This is an endothermic reaction and has the added disadvantage of introducing the impurities of the ore into the steel we are trying to purify. If we use pure oxygen for this purpose, not only do we avoid contaminating the steel, but by the exothermic reaction so obtained we increase the heat content of the bath and shorten thereby the time required for the process. If we use oxygen for combustion in the final stages of the process, we will be enabled to regulate the furnace atmosphere and thereby approach electric furnace conditions. This will enable us to make a highly reducing slag and obtain a product which should be equal in purity to that of the electric furnace.

Another very important application of oxygen in the open hearth plant and, in fact, in many other metallurgical plants, is in the manufacture of fuel gas. The substitution of oxygen for the air now used in gas producers will not only increase the efficiency of the producer by eliminating the necessity of heating large volumes of nitrogen, but it will give us a gas of much greater calorific intensity. It is also interesting to note that for domestic purposes a gas might be produced which will not only be materially cheaper than the water gas now so generally used, but will be of such high calorific value as to require very little enrichment by hydrocarbons to pass accepted city standards. In an investigation of this nature we should also look to the utilization of cheaper fuels. We are confident that much lower grade fuel may be used with oxygen to produce industrial gas, and advocate that research be conducted along this line with lignite, coke breeze, and other more or less undesirable materials.

The manufacture of ferro-alloys is in most cases accomplished only in electric furnaces. The oxides of the more difficultly reducible

metals, such as silicon, manganese, chromium, vanadium, molybdenum, etc., are not reduced to any extent, if at all, by carbon monoxide at temperatures available in the blast furnace shaft. Consequently, these oxides, if charged in the blast furnace, could be reduced only in the smelting zone by heat above the critical temperature. Ferro-manganese and some low-grade ferro-silicon is manufactured in the present blast furnace, but with an excessively high fuel consumption because of the high smelting zone requirements. The high reduction temperature of the other alloys render impossible their manufacture in the blast furnace with air blast. However, given a blast with higher oxygen content, we are convinced that not only should all of the ferro-alloys be smelted in the blast furnace, but that with proper regulation of the oxygen the fuel consumption should be very little more than the theoretical requirement. With this in view we made an analysis of the thermal requirements of the manufacture of ferro-manganese and find that by increasing the oxygen in our present furnace to only 26.3 per cent by weight we will increase production 75.8 per cent and decrease cost by 18.7 per cent.

The manufacture of ferro-alloys is but one of the large number of applications where combustion with oxygen will probably replace the electric arc. Nor will the application of oxygen be confined to ferrous metallurgy. We expect results in non-ferrous metallurgy and applied chemistry so numerous that the limitations of time will not permit of their mention. However, we feel safe in making the statement that nearly all processes depending for successful operation on extremely high temperatures, or processes in which a large portion of the useful high temperature heat is dissipated in heating nitrogen, will be revolutionized by the use of oxygen.

Discussion

President Howard: The paper is open for discussion.

Mr. J. P. Hubbell: I should like to ask Mr. Davis whether it is possible at this time to give any idea of the magnitude of a plant necessary to supply oxygen for a blast furnace?

Mr. Davis: In present blast furnace practice, a furnace requires from 30,000 to 50,000 cu. ft. of wind per minute. Just how far it will be practical to enrich this blast, and how much oxygen will be required, is not known. Enriching this blast to a comparatively small

degree will necessitate oxygen units larger than any at present available. The application of oxygen to blast furnaces, however, will eliminate the necessity for the hot blast stoves. It is believed that the saving thus effected will more than compensate for the expense of installing the oxygen plant.

Mr. Hubbell: Would a plant sufficiently large to provide a furnace with oxygen be likely to produce it at $3.00 a ton?

Mr. Davis: We believe so. Not only has our own committee made that statement, but I believe that Claude gives an equally low figure for oxygen with a large installation.

Mr. Hubbell: Have you any idea what the investment is likely to be?

Mr. Davis: Unfortunately I am unable to supply any idea of the investment necessary for the oxygen plant. The problems relating to the production of oxygen are in the hands of a committee of experts appointed specially for that work. Until the committee make a detailed report, little may be said other than that $3.00 per ton is their estimate.

President Howard: Have you read the report on this subject published last summer by the British engineers?

Mr. Davis: In that report they have dealt briefly with the existing practice in manufacturing oxygen, and have theorized considerably on the absorption process—that is, absorbing the air in different liquids. They are quite pessimistic. Their conclusion is that oxygen will be very beneficial, but they doubt if it can be produced by present processes. As a matter of fact, in their studies they give a certain minimum price for oxygen which will be necessary in order to show economy, but on analyzing those figures we find them to be a little high.

President Howard: Have you made any investigation as to the actual cost of production by existing plants?

Mr. Davis: We are gathering information on existing plants, but have nothing available at present.

President Howard: Is there anything which approaches the $3.00 a ton to-day?

Mr. Davis: When one considers that the total oxygen production of this country to-day, taken as a whole, would not be sufficient to supply one blast furnace, it becomes apparent that the manufacture of oxygen for metallurgical purposes and the present manufacture of

oxygen are two entirely different propositions, and that costs for one would hardly hold for the other.

PRESIDENT HOWARD: $3.00 a ton would only be effected by a very large installation, then?

MR. DAVIS: Yes; that would be the figure for a large installation.

PRESIDENT HOWARD: For furnaces in chemical works where one-tenth the amount used in a blast furnace is required it would be too expensive, then?

MR. DAVIS: I should not like to make any statement as to that. I do not think, however, that it would be prohibitive. The work done by the helium board and some of the developments which they have made, which are not as yet published, will have a great bearing on the oxygen situation. We believe that we are on the verge of very cheap oxygen.

PRESIDENT HOWARD: The whole key to the situation is the price of oxygen, then?

MR. DAVIS: Yes.

PRESIDENT HOWARD: Everybody has been longing for it, and everybody can imagine the possibilities in their own respective fields, so it is only a question of actually getting it. As soon as you are sure of that, the use will increase with enormous strides.

MR. DAVIS: I think I differ with you a little on that statement. I believe that the oxygen manufacturers have never had the incentive to make the developments for producing cheap oxygen. If a steel manufacturer should go to the oxygen man and say, "We want cheap oxygen in large quantities," I believe the oxygen man would make the effort to get it, but as I understand it nothing of that nature has ever been done. There has not been sufficient incentive or enough of a campaign really to start progress in this line.

MR. A. H. HOOKER: If there were cheap oxygen, would it be necessary to utilize both oxygen and nitrogen at the same time?

MR. DAVIS: That has not been considered necessary. Of course, if you can utilize both, that will be——

MR. HOOKER: That would be the really ideal thing, to utilize both oxygen and nitrogen, at the same time?

MR. DAVIS: Yes; that would probably be the cheapest method.

A MEMBER: When you refer to oxygen, what do you mean?

MR. DAVIS: 99 per cent pure.

PROF. R. T. HASLAM: While I personally believe that cheap oxy-

gen will be very beneficial, I think we have overlooked the difficulty of using it. I am not a metallurgist, and am probably talking outside my field, but I understood that in iron blast furnace operation, high temperature at the tuyeres gives larger amounts of impurities in the iron, and if you use oxygen you will get these higher temperatures. It is possible to-day to go to higher hearth temperatures by increasing the temperature of the hot blast. Another point is in connection with the use of oxygen in a gas producer. Here the tremendous amount of heat liberated by the interaction of the fuel with the oxygen will have to be absorbed by the decomposition of steam. But as long as there is any appreciable amount (one-third per cent) of oxygen in the gas going up through a fuel bed of a producer, so long will the steam remain undecomposed. Looking at it in another way, the oxygen will be consumed in the first 6 to 12 inches of the fuel bed, while the steam will pass through this oxidizing zone undecomposed. The steam will only be decomposed in a reducing zone above and separated from the oxidizing zone. Consequently, if oxygen-enriched air is used in an ordinary gas producer, severe clinkering will occur to such an extent that continuous production will be impossible. Oxygen-enriched air can, of course, be used in a slagging type of gas producer, but, owing to the difficulty of disposing of the slag, I do not think industries other than steel will look with favor on this type of gas producer, at least at the start. I really believe that cheap oxygen will be very beneficial, but, on the other hand, I do think that we have overlooked the real serious difficulty of using it.

Mr. Davis: On the question of temperatures, we do not expect to have any higher temperatures when using oxygen-enriched blast than are obtained to-day in ordinary blast furnace practice. When hot blast stoves were first used, the total heat introduced into the furnace was increased by about 18 per cent and the available high-temperature heat was increased by about 40 per cent. The temperature in the furnace, however, remained the same, and the additional heat was absorbed by additional material charged per unit of coke. The critical temperature is determined by the slag viscosity to a greater extent than by the total heat in the furnace. With the introduction of oxygen-enriched blast, we expect to have conditions similar to those which accompanied the introduction of the hot blast; that is, we will increase the amount of available high-temperature heat. In this case the increase will be accomplished by decreasing the amount

of heat carried away from the high-temperature zone and, as was the case with the hot blast application, this additional heat will be absorbed by additional burden.

In regard to the gas producer application, I have no personal knowledge of the slagging type gas producer. I have always felt, however, that it is an efficient machine which has suffered a large amount of abuse. We had not considered a gas producer of the slagging type, but had expected to lower the temperature in a combustion zone by decomposition of steam.

Prof. Haslam: I believe that type of gas producer has been abused because it has not been understood.

Mr. Davis: When you consider that all our present equipment has been designed on the principle of using blast carrying about 80 per cent inert matter, it would not be surprising to find that some of this equipment will not be readily adapted to the use of a more active blast. The indications are that as we increase the oxygen beyond certain limits it will be necessary to re-design much of our equipment.

Prof. Haslam: I wondered why they did not use a hotter blast now.

Mr. Davis: To answer Prof. Haslam's last question will require some description of the operation of the blast furnace. In the first place, the limiting factor in the thermal operation of the furnace is found in the amount of high-temperature heat in the smelting zone. If the amount of this heat decreases unduly, the furnace will become irregular and ultimately "freeze up." The operator has two methods of increasing this high-temperature smelting heat, first by increasing the temperature of his blast, secondly by charging more coke. Any additional coke charged, however, must pass from the top of the furnace to the smelting zone before it can effect any change in smelting conditions; normally this requires from ten to fourteen hours. If the furnace is cold, the operation will be slow and more time will be required; in fact, if conditions are very bad, the furnace may freeze completely and the additional coke never reach the zone of trouble. On the other hand, if the operator can increase his smelting heat by heating his blast one or two hundred degrees higher, he will get almost immediate relief, where if he were using his maximum blast temperature at all times he would save coke on normal operation, but would probably lose his furnace when conditions become irregular. His practice, therefore, is to use colder blast and burn the addi-

tional coke, considering this extra coke as insurance and a good investment.

Mr. A. E. Marshall: In speaking of the use of oxygen in open hearth furnaces, I am unfamiliar with this use and would inquire if there is sufficient differentiation in the combination of iron and oxygen and the non-ferrous materials and oxygen to insure not burning up the iron?

Mr. Davis: I should like to state that I have seen an application of pure oxygen to steel making. In one of the plants manufacturing a high-chromium, low-carbon steel they were confronted with two possibilities: the first was to buy a low-carbon ferro-chrome, which is very expensive; the second was to use the ordinary high-carbon ferro-chrome and eliminate the carbon in the furnace. A practice has been developed in which they are able, by the use of oxygen in the bath, to make the desired grade of steel, using the comparatively cheap high-carbon alloy. Their practice is as follows: They melt their bath and desulphurize as usual, next they prepare a basic slag, and add their chrome alloy. As soon as this is melted they have a bath with the desired chrome content, but high in carbon. The next step is to introduce a calculated amount of oxygen into the bath through iron tubes. This oxygen literally burns out the carbon and in so doing heats the bath very rapidly. The chromium is also oxidized, but is retained as an oxide in the slag. The next step is to reduce the slag, throwing the chromium from the slag to the bath as metallic chromium, and the resulting product will be found to be high in chromium and low in carbon. This process not only permits the use of a very cheap alloy, but also effects a saving in that the intense heat generated in the bath by the oxygen addition shortens the time requirements considerably.

President Howard: Dr. Nichols, can you add anything to this discussion?

Dr. Wm. H. Nichols: Mr. President, as you yourself well know, one of the most interesting things is the statement that the Bureau of Mines believes it can produce oxygen at $3.00 a ton. Mr. Davis has enlarged on our applications. Every chemical engineer in the room can think of a great many applications which such low cost would make possible. I am sure we will all watch this development with great interest.

Dr. R. B. Moore: I had not intended saying anything, but I

don't want any misapprehension to get out. In the first place, speaking for myself and not for the rest of the committee, I do not think that we shall have oxygen at $3.00 a ton in small quantities very soon. Therefore, when it comes to ordinary chemical engineering processes used in small plants, I think we can forget that for some time. That $3.00 a ton applies only to oxygen in large quantities, such as would be available for blast furnaces of the size already mentioned by Mr. Davis.

As to how soon that will come, it is difficult to say, but I will give you an illustration. Before the war helium cost $2,000 a cubic foot, and there were about 15 cubic feet in the whole world. When we were doing our experimental work in Texas, before we were able to use the large-sized production plant, the smaller plants processed about 700,000 cubic feet of gas a day each, and it cost us about $300 per 1,000 cubic feet for helium. Sometimes it went up to $500 for helium during the experimental stage. To-day we are producing helium for $80 to $100 a thousand. We have obtained it on this size of plant at $80 to $100, and it has been as low as $70 a thousand, not counting overhead. That is the actual producing expense. I have myself, before a Congressional committee, said that helium will ultimately be produced for $30 a thousand, and if we had not made statements of that kind we would not have gotten several million dollars out of Congress that we did get. [Laughter.] In other words, we have to give our judgment based on our best technical knowledge as to what can probably be done under certain specified conditions, and unless a man does that sometimes he will never get anywhere. I am absolutely confident that we will make helium for $30 a thousand. We have a little plant down at Fort Worth to-day which processes natural gas at the rate of 300,000 cubic feet in 24 hours as against five million on the big plant. That little plant can produce helium as cheaply as the big plant, and it can take the tails from the big plant and make a 70 per cent extraction on them. If you multiply a plant 50 or 75 times and eliminate all questions of overhead and large profits, it will be hard to say where you will come out. But somebody has got to make an estimate, so that the two extremes can get together. You have to tell the steel man something about what he may expect, and then when you get him interested you have to tell the commercial oxygen man, "Here is something that the steel men are interested in, now get busy and make it." We

believe that the second report will add to the evidence in the case. We can not give you the details now, because we are not ready. [Applause.]

Mr. Robert D. Pike (communicated): Passing by the assumption that oxygen can be made for $3.00 per ton, which is open to serious question, and assuming for the moment that this low cost can be attained, it would no doubt be true that many interesting applications in metallurgy would present themselves; but we must guard against arriving at definite conclusions regarding these applications on purely theoretical grounds. The successful application of oxygen-enriched blast would have to be worked out in a practical way in each case and this will be an arduous undertaking requiring the expenditure of much time and money. The specific effect of the much higher flame temperature upon both the reactions and refractories may well prove to be the determining factor rather than saving in heat units effected by a reduction of the nitrogen in the gases of combustion. While high flame temperature in itself is desirable, because it not only results in a greater amount of available heat above the ruling hearth temperatures, but also results in a greater delivery of heat per unit volume of combustion space, it must be remembered that this latter advantage can only be realized provided this unit area of material being treated can absorb the additional flow of heat in the unit of time. In short, additional heat propagation must be matched by additional transfer of heat to the seat of the reaction without destroying a portion of the reacting material or the refractories, or both.

In his concluding paragraph Mr. Davis includes among those processes which will be revolutionized by oxygen enrichment "all processes in which a large portion of the useful heat is dissipated in heating nitrogen." All combustion processes would be included in this category, but a simple analysis of a few typical combustion processes will serve to show that the author is too optimistic over the advantages of oxygen enrichment. This is true largely because in most high-temperature combustion processes the principle of regeneration or recuperation is employed, whereby the heat in the gases of combustion leaving the hearth or combustion zone is utilized in preheating air for combustion. The open hearth steel furnace and glass tank furnace fall into this class. In another class, of which the rotary kiln for burning Portland cement clinker is the chief example, the heat in the

very hot gases leaving the lower portion of the kiln is partially utilized in heating the fresh charge by a counter-current heat interchanger.

The following represents a typical heat balance of a rotary kiln:

	Per Cent of Heat in Fuel
Heat usefully employed	25
Sensible heat in gases	40
Sensible heat in clinker	15
Radiation losses by difference	20
	100

The unit heat usefully employed amounts to about 370,000 B.t.u. per bbl. of 376 lbs. of clinker, the total heat in the fuel being about 1,480,000 B.t.u. It may be presumed possible that, in using an oxygen-enriched blast, the capacity of a given kiln would be increased in proportion to the outside area of apparatus exposed, thereby reducing the proportion of radiation losses in the above balance, but this is merely speculative and can not be sustained by any available data. Neither the heat usefully employed nor the sensible heat in the clinker can, of course, be changed, so the only large heat saving which would result from the use of oxygen-enriched blast would be the sensible heat of the stack gases. All of this could not be saved, but to use round numbers let us assume that it could be by the use of pure oxygen. This would mean a saving of 529,000 B.t.u. per bbl. of clinkers. With coal at $4.00 per ton the million B.t.u. is worth about 15 cents, so the saving would be about 9 cents per bbl. The amount of fuel still required to burn the clinker would be 1,480,000 — 592,000 = 888,000 B. t. u., and this would require about 158 lbs. O_2, allowing for no excess. At $3.00 per ton this would be worth 24 cents. The loss due to the use of O_2, at $3.00 per ton would therefore be about 24 cents — 9 cents = 15 cents per bbl. of clinker.

Similar results will be obtained from calculating most simple combustion problems.

In view of these considerations, I feel that the use of O_2 for combustion will parallel the development of the arc electric furnace and will be in those fields where unusually high temperatures are required, or in such uses where the absence of nitrogen has advantages other than those which arise from saving its sensible heat content.

Mr. Davis (communicated): I agree with Mr. Pike that the successful application of oxygen-enriched blast will have to be worked

out in a practical way, and that theoretical figures as to the results do not constitute conclusive evidence. The U. S. Bureau of Mines is preparing to conduct experiments along these lines in the not distant future. It would be rather foolhardy, however, to embark on an experimental campaign of this nature without first outlining a program, and then using all accepted theories available to predict the results to be expected in such an investigation. The report on the study of the application of oxygen to metallurgical fields recently issued by the Bureau, which forms the basis for the paper under discussion, is the result of this preliminary study. Neither the report nor the paper were presented as conclusive evidence, but simply as guides to be followed in the experimental campaign.

As to Mr. Pike's question of the ability of the "unit area of material" to absorb the additional flow of heat in the unit of time: when we enrich the oxygen of the blast we will at the same time increase the amount of ore charged per unit of coke. We will, therefore, be increasing the quantity of heat-absorbing material per unit of heat. If we did not do this, we would undoubtedly have trouble from too high temperatures. As it is, we do not expect any higher prevailing temperature in the smelting zone than in present practice. I might add again that this same procedure was followed when hot blast was first used, and that as a result the observed hearth temperature was not changed by the change in practice.

The statement in the concluding paragraph should read "all high-temperature processes in which a large portion of the useful heat is dissipated in heating nitrogen." This may be a rather broad statement, but is not intended to include all combustion processes by any means. It is not expected that oxygen will prove of value in many of the comparatively low-temperature combustion processes. The cement kiln would fall into this group.

With reference to the open-hearth furnace, we do not expect to be able to effect fuel economy with the use of oxygen; in fact, our present refractories will not permit of higher temperatures being employed. If, however, we can develop better refractories, it is believed that economy will result from the use of oxygen. This economy will probably not be effected in the fuel cost, which is a small portion of the total. The main feature, and one which is of greater importance than fuel, would be materially decreasing the time for the process, and it is believed that this could be accomplished by using oxygen.

POLICIES, PROBLEMS, AND PRACTICES OF THE BUREAU OF STANDARDS

By GEORGE K. BURGESS, *Director*

Read at the Washington Meeting, December 5, 1923

First, as Director of the Bureau of Standards, I am glad most heartily to welcome you, the members and guests of the American Institute of Chemical Engineers, to the Bureau, and trust you will take the opportunity to visit the Laboratories in as great detail as you may wish. All our work is open to your inspection and we invite comment on anything you may see.

Second, in view of the fact that several papers descriptive of this Bureau's activities are being given by members of the staff, I am sure you expect of me but the briefest of statements concerning our "policies, problems, and practices." This subject was chosen by your local committee and they might have added "promises, performances, and publicity" to the title, and even included "principles, perplexities, and perturbations," but perhaps these come as subheadings.

The cardinal principle of our policy is to live on good terms with the other members of the family in the Department of Commerce, maintain cordial relations with our cousins in the other government establishments, and be of the greatest possible service to the American public to whom we are responsible for the wise expenditure of the funds they put at our disposal in matters pertaining to standards.

Our greatest problem, of course, as everywhere else, is the one of personnel; but in an institution devoted largely to scientific research the securing and maintaining of an adequately trained personnel, possessing vision and producing capacity along several lines, that must be kept at least fairly well balanced, is vital to its success and standing. We have other problems, of course, some of them common to all public and most private institutions, such as how to increase our income; and we have some special to ourselves, such as securing title to the land across which is our only practicable main entrance, and building a much needed modern power plant that would easily pay for itself out of the savings in operation and other costs it would effect.

Your committee could hardly have had reference to scientific and technical problems of the Bureau, for they are literally legion and are referred to briefly in the annual report of 330 pages of the Director to be issued December 15. This multiplicity of problems is in itself one of the "problems" of the Bureau. The question has been asked, "How do you decide what problems to take up?" The answer is not easy; it is a good deal like a garden in which you plant seeds and raise flowers, shrubs, vegetables, and trees of various sorts and even weeds, which last, of course, you did not plant. Room has constantly to be made for new plants that neighbors bring in and for natural developments from the original stock, and there are annual plantings also; neighbors seeing what a fine garden we have ask us to start plants for them and to make experiments, some of which take up considerable space and are expensive, requiring elaborate greenhouses and other special housings; and it is always difficult to say "no" to a neighbor. You may have planned your garden originally along simple, logical lines, but after twenty years or so it has spread over an unexpectedly large area, and requires a large number of skilled gardeners; you have built up a business of supplying flowers, fruits and vegetables, and the public is constantly increasing its demands for more varieties in greater numbers. Such, as I see it, has been the growth of this Bureau.

We have no desire to trespass or poach on other persons' property and we are glad to have others raise their own flowers and vegetables. We are specialists, however, in certain species in which we take great pride, and for our own stocks we like to be recognized as occupying a preferred position.

The Bureau deals with five classes of standards: (1) Measurement; (2) Constants (physical or chemical); (3) Quality (of materials); (4) Performance (as of machines); (5) Practice (as of service codes).

It has five lines of activity or "practices" as related to these standards and dependent subjects in physical science, technology, and engineering: (1) Testing; (2) Research; (3) Inspection; (4) Specifications; (5) Codes. As to the testing work of the Bureau, I should like to say a few words, since there has arisen apprehension occasionally in the minds of some, particularly among chemists, which I may illustrate by the following letter:

"The Bureau of Standards is apparently running a commercial Testing Department of increasing importance so far as we are concerned. Apparently any one can send samples of fabrics, petroleum products, paints, cement blocks, bricks, metals, alloys, etc., and have them tested either for nothing or for such a small fee that it is difficult for private laboratories to compete.

"We object to this system of running a Government Department and think your Bureau should limit itself to such testing that may be required to

"1st—Settle a disputed technical point of some importance and not a mere dispute between chemists or other testing laboratories.

"2d—Such work as can only be done in your Bureau on account of special testing machines of larger capacity than those owned by private parties.

"3d—Such work for States and political divisions thereof that you are compelled by law to perform.

"We would be glad to have an answer to this letter at your early convenience."

This may be answered by a few figures taken from the forthcoming annual report:

	Total	Tests for *Government*	Tests for *Public*
Materials	Chemical analysis	4,886	11
	Cement (all)	7,710	1
	Metallurgy	1,260	21
Instruments	Weights	892	4,085
	Capacity	2,409	7,152
	Thermometers	1,951	18,178

from which you will note that for the public the tests of materials are insignificant while those of instruments are relatively high. In other words, the Bureau does for the other government establishments routine testing work on materials but refuses this service to the public since it may be obtained satisfactorily in commercial laboratories; but it does execute for the public those tests of instruments which cannot be obtained elsewhere. Even in the instrument field we try to limit ourselves to the higher grades of apparatus.

In the field of research, particularly as related to industry, much of our work is done in cooperation with advisory committees of

which there are about 100; in several instances also the Bureau acts as a unit in a Joint Committee and does its allotted share of the experimental investigation and reports through the group, using some technical forum for presentation, as the American Society for Testing Materials, for example. We are in favor of the group system of research for many types of problem and feel the system of advisory committees has been of the greatest advantage to the Bureau in aiding it so to orient its work as to meet with the approval of the industry or interest concerned. Our inspection work is at present limited mainly to cement, sugar and lamps for the government departments and to field items in weights and measures such as track and mine scales. We are glad we have no police powers.

The specification work of the Bureau the past two years has been greatly extended, largely due to the establishment of the Federal Specifications Board, of which the Director is ex-officio chairman, and many of the staff are members of its sixty committees. Secretary Hoover has suggested the issuing of a Dictionary of Specifications which shall be a Buyers' Handbook and this compilation is well under way. The specifications already in our files would make ten volumes of the Encyclopedia Britannica. So we have quite a problem here, as you can see.

As to systems of weights and measures, the Bureau is not an active advocate for any one, but will administer impartially all legal systems in use. Similarly, as to service and safety codes, in the formulation of which the Bureau has been very active, it is our desire to be of greatest service to the community, and in this field, as in some others, we believe we have been able to play an impartial rôle, bringing the producing and consuming interests together and often representing in a technical capacity also the seldom articulate public, especially in matters relating to public utilities. Most of the work on safety codes and service codes is headed up in the American Engineering Standards Committee.

In matters of new legislation of general interest, it is the policy of the Bureau, as of the whole Department of Commerce, to furnish technical information, as may be desired, but not to take an active part in educating the public or participation in publicity campaigns to influence public opinion.

As to publicity of the Bureau's own work, we have often been told by many of our friends, that we are too indifferent to the ap-

plications in practice of the results of our investigations. Knowing this to be a fact we can perhaps help to remedy this situation, but the fact must be faced that the productive scientific man is often indifferent to what application is made of his discoveries. The solution would seem to be that some one else has to make the application.

And this brings us to the last problem we shall have time to consider to-day, and the question is often put in this wise, What proportion of the Bureau's available resources should be devoted to "pure" science? It is difficult to give a numerical answer to such a question and there are many other than scientific questions that enter into the problem. It is intimately associated with the personnel problem, and so we return from whence we started. I can assure you we shall be glad of the advice of members of this Institute on this question of best balance of our work, as also on many others in which we may have an interest in common.

THE CHEMISTRY WORK OF THE BUREAU OF STANDARDS

By W. F. HILLEBRAND *

Read at the Washington Meeting, December 6, 1923

Without attempting to limit my remarks to the applications of the chemistry work of the Bureau of Standards to chemical engineering, it is my intent to present to you rather a survey of what has been done and is being done in chemistry at the Bureau and to let each one of you draw your own conclusions as to where, how, and in what degree this work may or does affect you professionally.

When I entered upon duty here in July, 1908, succeeding Dr. Wm. A. Noyes, the number of chemists could be counted upon the fingers of one hand, and no clear policy or program for the development of chemistry had been formulated. A certain small amount of testing was being done for the Government here in Washington and some high-grade research had been carried out. The foundation had also been laid for what has since become an important asset to the Bureau and a model for imitation abroad. I refer to the preparation and distribution of standard samples. The initial step in this field was the taking over, from the American Foundrymen's Association at their request, of the distribution of a few samples of cast iron which had been compounded with special reference to the needs of industry and with the utmost precautions to secure homogeneity and freedom from external contamination. These samples were used as a check upon analysts and the methods of chemical analysis employed in foundries and steel works. My previous long experience as an analyst enabled me to perceive at once the advantages and importance of this line of work, and it was therefore not long before I determined to devote the major energies of the chemical force to its extension and to let the general policy develop by degrees as the needs became manifest.

I could spend hours in describing the growth of our standard sample work from a beginning of irons and steels through the

* Chemist in Charge, Bureau of Standards

gradual addition of ores of iron, manganese, and zinc, a raw mixture for Portland cement, various special steels and ferros (the last only just started), brasses and bronzes, pure organic materials for calorimetry (sugars, naphthalene, and benzoic acid—the last also in demand as an acid standard in volumetric analysis), sodium oxalate for oxidimetric analysis, cement powders for grading sieves, and certain metals for use in fixing melting points. The recital would be for some a fascinating story of difficulties met and for the most part overcome in the choice, preparation, and analysis of the samples, but it would lead too far afield to offer even a mere outline for the present occasion. Suffice it to say that the yearly demand for the 62 items now in stock calls for about 5,000 specimens, which are sold at different prices, except to Federal and State or State-aided institutions which receive them free. Prior to the war we had numerous foreign clients. The foreign demand is now in part met by organizations in England and Belgium, in the furtherance of whose efforts and aims we have actively co-operated.

Mention should be made here of one phase of this work which is not yet generally understood. This is, that the moneys received for the samples can not be used as a revolving fund to support the work, but revert to the Treasury. Hence, in order that a work of such importance to many industries should not lapse or at least suffer greatly, it has been necessary to seek aid from Congress. At present a special fund of $10,000 from that source is available which should be increased to $15,000 at least, in order to make the work practically self-supporting and unaffected by periodic pressing money needs of other fields of Bureau activity.

How far the increasing demand for these samples will lead it is impossible to say. Our choice is usually made upon the solicited advice of technical organizations or after consultation with specially informed individuals. Now and then we find it impossible to meet evident needs, as for instance for a coal sample, and in general for those materials whose moisture content fluctuates markedly in step with that of the air.

Passing now to another phase of our chemical activity, I will devote some space to the testing of supplies purchased and of material submitted for test by the several branches of the Government Service. But first a word or two as to the policy which the Chem-

istry Division has consistently followed with regard to testing for the public.

Although we have the right to make such tests and to charge for them, it has been felt that to accept work of this kind would adversely affect the Bureau in two ways. First, by bringing such a flood of it as to hamper greatly the proper work of the Bureau, and, secondly, arousing justifiable hostility against the Bureau on the part of commercial analysts, with whom we would be competing. Hence, the requests that come to the Chemistry Division for tests are refused, unless the circumstances are so peculiar as to justify making an exception either because commercial analysts have failed to agree or because the Bureau would derive useful knowledge from the test. In the first of these two cases it is customary for us to ask both parties to a controversy to unite in the request, to agree upon the sample to be tested, and also to abide by our decision. In the second case it may be that no charge is made.

Little of the large amount of testing work done for the Government can with propriety be called routine work as this term is ordinarily used in factory laboratories. Not only are numerous difficult tests made on the samples examined, but from the results of such tests conclusions are drawn as to the quality and suitability of the materials tested, and this often calls for supplementary work which may be of a research nature.

The major part of such testing is done by three of the seven sections of the Chemistry Division, and, by reason of the knowledge gained by constant contact with a great variety of widely used commercial products, the staffs of these sections are well qualified to formulate specifications for the use of the Government. Once established these usually commend themselves to the consuming public and are adopted soon or late by other large purchasers, such as states or municipalities, either as written or after modification. It should be emphasized that our specifications are never put forth without first conferring with producers and consumers. Of such specifications a large number have been promulgated, not all emanating from the Chemistry Division, covering paints and paint materials, detergents, rubber manufactures, chemical lime, and battery acid. Numerous others are in preparation.

Out of the long list of materials of interest to engineers that are constantly undergoing test, I will single out a few for special mention.

Rubber.—In its various uses as steam, water, suction, and oil hose, as a constituent of packings, as valves and as tires, rubber may be called an engineering material. Its strength, its serviceability for a particular purpose, and its durability of life depend upon its chemical composition. Chemical investigation is essential to the success of any study of the properties and behavior of rubber. The Bureau has little reason to be ashamed of the achievements of its chemists in the chemistry of rubber. Its methods of analysis formed the basis of the analytical scheme provisionally adopted by the Rubber Division of the American Chemical Society, which made but two or three additions to and few changes in the procedure as written for the guidance of our own chemists.

Protective Coatings.—As protective coatings for a great variety of structures, paint and varnish are of the utmost importance in nearly all engineering problems. The widely used slogan, "Save the surface and you save all," is effective because it concisely expresses a well-known fact. The work of the Bureau in studying and improving methods of analysis of pigments, oils, varnishes, etc., has been of great use to both manufacturers and users of such materials. It may safely be said that the bulk of the work in preparing the standard methods of analysis of numerous pigments adopted as standard by one of the important national engineering societies was done at the Bureau. The specifications for paints prepared here and adopted as U. S. Government Standards cover a wide enough variety to meet most of the needs as protective coatings. They are admitted to be the best specifications available and are widely used in our country and to an appreciable extent in some foreign countries.

Our study of the properties of bituminous materials for use in roofing and waterproofing will, it is hoped, soon result in the development of a complete set of Government specifications.

Portland Cement, Etc.—In connection with Government work on rivers and harbors, reclamation projects, the Wilson Dam at Muscle Shoals, and other constructions, hundreds of analyses of Portland cement are made. Lime, gypsum, and related materials are analyzed for the engineering and ceramic sections of the Bureau.

Detergents.—Besides making hundreds of analyses of detergents each year, our chemists have prepared specifications for these in cooperation with the manufacturers, and participated largely in the

preparation of the standard methods for the analysis of soap and soap products adopted by the American Chemical Society.

Miscellaneous.—Among other materials tested and studied are lubricants, writing and typing materials, boiler compounds and scales, anti-freeze solutions, compounds for sealing steam and hydraulic lines and for extinguishing fires, brines for refrigerating plants, balloon fabrics for permeability, galvanized and other coated metals for thickness and continuity of coating and resistance to corrosion, airplane dopes, and many others. Our services on these materials are seldom limited to chemical tests, but often include technical advice of the most varied character.

Most of the testing referred to involves research of one kind or another and the closest touch with technical societies, but in addition to this there are divisions whose main work is in research.

Metal and Ore Analysis.—One has to do with the study of methods of inorganic analysis with special reference to metals, alloys, and ores. Much of this originated with our standard sample work. The very nature of this called for detailed study of the limitations of methods and of improving or devising methods for the certain detection or the exact determination of extremely small amounts of numerous elements to meet the growing demands of industry and of scientific study. In pursuance of this line of inquiry many papers have been published that are well calculated to help the analytical art, and much time has been spent in helping to prepare the standard methods put out by one of our engineering societies.

Platinum Metals.—Another field of research covers the metals of the platinum group. Thanks to an appropriation of $15,000 for this purpose the Bureau is well supplied with all the metals of the group except ruthenium, supposedly the least important as it certainly is the least abundant of the metals of the group.

This research is a particular pet of my own and grew out of a situation that obtained a number of years ago when the quality of much of the platinum ware upon the market gave just cause for frequent and loud complaint. Its object is to determine what metals of the group and what combinations of them are most suitable for chemical ware and physical appliances. This presupposes the possession of each metal in a pure state and this is again dependent upon the ability to carry the refining to an ultimate limit and to be able to know with certainty when that limit has been reached and how pure

the final product is. Marked success has attended our efforts thus far in this direction. We have learned how to analyze platinum ores and alloys and have made most of the metals practically spectroscopically pure. The important physical constants of these pure metals will be determined in some of the other divisions of the Bureau, and then will begin the preparation and study of binary alloys and later of those more complex. The value of close co-operation between chemist and physicist is well exemplified by this research.

Physical Measurements in Chemical Analysis.—The reference to spectroscopic purity just made leads me to point to the growing tendency to utilize physical measurements as a means of determining the purity or composition, quantitative as well as qualitative, of substances. Spectroscopic testing is particularly useful as a preliminary to quantitative analysis, for thereby one is often saved much vain work by the ordinary methods of test and on the other hand may be given important information that elements are present which might easily be otherwise overlooked.

Electrodeposition of Metals.—A third line of research is in the field of electrodeposition of metals. The purposes of this research are (*a*) to determine the fundamental principles, especially those which govern the structure and properties of the deposits, (*b*) to develop methods for the analysis and control of electroplating and electrotyping solutions, and (*c*) to furnish to interested Government departments, manufacturers, electroplaters, and others, information and advice. Owing to the fact that there are comparatively few persons with technical training connected with the electroplating and electrotyping industries, frequent visits to plants and lectures to appropriate groups are necessary and helpful. In addition to the contacts thus formed the section keeps in close touch with the industry through the research committee of the American Electroplaters' Society, which meets here at the Bureau twice a year. Progress has been made in throwing light on hitherto obscure matters and otherwise helping the industries concerned. Thus far attention has been mainly given to nickel and copper deposition, with that of platinum as a secondary though important study.

Chemistry of Gases.—Our work upon gases is of an extremely varied character. Excluding that relating to the presence, effect, and determination of gases in metals, which will be referred to later, it includes, in addition to several lines of experimental research, the

assembling and critical review of technical data on the physical and chemical properties of the important gases; on gas analysis; on the production, separation, purification, utilization, and handling of gases for many purposes. It is our constant object to promote a closer co-ordination between the fundamental data of physics and chemistry and the practical engineering and economic factors which determine the success of operations involving gases.

The study and development of methods of gas analysis is one of our major lines of work. Several contributions have been made to the subject in the form of new apparatus and methods, some of which have come to have rather extensive use. About thirty publications, mostly in technical journals, have been made on subjects within this field.

The most important development has resulted from the study of automatic methods of gas analysis, particularly that depending upon thermal conductivity. This method gives an electrical effect of sufficient magnitude to operate existing types of recorders, relays, and other automatic controls. Apparatus has been constructed and supplied to other Government establishments for at least six different purposes and has been introduced into several commercial industries by the Bureau. This system of analysis has taken precedence, in our own research work, over all other methods except the usual volumetric ones, and is of nearly equal importance with them. The future field of application of this method, particularly in automatic control work, appears to be very great. This is another instance of the growing use of physical measurements for chemical analysis.

A study of the phenomena of the absorption of gases in liquids has been undertaken, particularly absorption by liquids with which the gases react chemically. The work already done has been in the nature of establishing basic principles which can later be applied to engineering equipment on a commercial scale. It is planned to make the study of gas absorption the first of a series of experimental and theoretical studies of the chemical engineering processes generally used in gas work.

A research has been begun upon the separation of gases by fractionation, both for analytical and preparative purposes. The results of this research should have important applications in several industries. The first problem dealt with is the development, in co-opera-

tion with the Natural Gas Association, of a standard method for determining gasoline in natural gas.

Plans have been made for a study of several of the more important industrial gas reactions. Reaction velocity and equilibria will be special objects of study; but relatively much more attention will be given to velocity than is customary in work of this kind. Several novel methods of attack in the study of groups of reactions have been planned; and a successful solution of the problems involved will be indicated only when the observed data are consistent among themselves and in agreement with known physical-chemical principles.

Three of the more important methods of producing hydrogen have been studied with great thoroughness. The research resulted in what is in many respects a new method of applying the reactions of the steam-iron process. It is believed that the new method will render possible the production of hydrogen as a by-product of gas manufacture and its economical manufacture from natural gas. Combined, these will make possible the rapid expansion of hydrogen manufacture and probably of nitrogen fixation to meet any emergency.

Probably the most important of all the gas researches, because of its direct relation to the public, is the study of the safety and efficiency of gas appliances. At the present time our efforts are devoted principally to determining the minimum requirements of safe practice and the development of methods of determining compliance with such requirements.

Dye Standardization.—The dye work of the Chemistry Division comprises the preparation of dyes of known purity to serve as standards for spectrophotometric measurements and for checking the accuracy of chemical methods of examination. These methods are being supplemented by actual dyeing tests on yarns.

It is planned to continue the above work and to make as comprehensive a survey as possible of commercial dyes. This conflicts in no way with the dye research that is done in the Bureau of Chemistry, Department of Agriculture.

Outside Co-operation.—Nearly all sections of the Chemistry Division co-operate extensively with committees of technical societies and with other agencies. The Division is represented on many committees that are engaged in scientific work, and in a number of instances its members are chairmen of committees. Major organiza-

tions with which such co-operation was had in the past year are: American Society for Testing Materials; American Chemical Society; American Engineering Standards Committee; Federal Specifications Board; American Concrete Institute; American Electroplaters' Society; Paint and Varnish Manufacturers' Association; Interdepartmental Conference on Chemical Lime; Natural Gas Association; American Foundrymen's Association.

Much travel was undertaken for purposes of inspection of field tests and other conditions of corrosion, study of plant operations, attendance at meetings of committees, etc.

Thus far I have spoken almost altogether of the work of that unit of the Bureau called the Division of Chemistry. Work in chemistry is not restricted, however, to that unit. I will outline very briefly several lines of chemical research carried on in other divisions.

Sugar Chemistry.—The work in sugar chemistry originated from the necessity of examination and certification of the quartz plates used for the control of the saccharimeters employed in the appraisal of raw sugar by the Treasury Department for the purpose of tariff assessment. This led to an examination of the fundamental constants and standards which are in daily use in the industry. An error of over one-tenth per cent was disclosed in the 100° point of the saccharimeter and one-half per cent in the Clerget Constant. Many other analytical problems followed as a logical necessity.

The work now has been extended to include nearly every phase of sugar chemistry and sugar engineering. In the purely chemical lines the studies include the configuration, properties and preparation of rare sugars, and their derivatives. These studies are not only academic, but the results are frequently applied to bacteriological and physiological problems. Standard samples are also prepared. One research on glucose, undertaken as a purely analytical investigation, has led to the revival of a previously unsuccessful process for the manufacture of pure glucose sugar which is now being produced on a very large scale at a low cost and has a purity of 99.8 to 99.9 per cent.

The engineering problems include elimination of impurities, filtration, vacuum evaporation, crystallization, and centrifugal separation of sugar products on a scale of industrial magnitude.

Sugar products are to a great extent graded upon color. The Bureau has investigated these colors and has proposed standards

based on spectrophotometric measurements. These standards are now being submitted and will probably be adopted by three great industries—namely, the refining industry, the beet sugar industry, and the glucose industry.

Metallurgical Chemistry.—The study of the chemical composition of metals and alloys and of the chemistry involved in metallurgical smelting and refining operations is the scope of the work of a group of chemists attached to the Division of Metallurgy of this Bureau.

This section of the Bureau has given particular attention to the purification of iron, to the melting of such iron without the introduction of more than traces of the usual metallurgical impurities, and to the preparation of alloys of this material with varying proportions of carbon, manganese, and sulphur.

The same group of chemists co-operates in the work of the Bureau on the platinum metals by taking charge of the melting and alloying of the extremely pure metals.

The greater part of the work of this section, however, is devoted to the study of methods of determining gases and non-metallic impurities in metals, and to the correlation of the physical properties of metals with those constituents whose presence is frequently overlooked in determinations of chemical composition. This work is obviously closely connected with the refining and deoxidative processes of metallurgical practice.

Battery Investigations.—The growing importance of dry cells and storage batteries has led to numerous requests for tests and information and a great deal of research has been done in consequence in co-operation with manufacturers and electrical engineers. While most of this work is physical, an important part of it is chemical. A speedy and rapid method has been developed to measure the rate of sulphation of storage battery plates and to determine quantitatively the effects produced by various impurities in storage battery electrolytes. This last work has led to the drawing up of a specification for battery acid. Methods have also been developed for analyzing battery electrolyte and the contents of dry cells.

In the foregoing I have sketched as briefly as the allotted time and space permitted, that part of the Bureau's work which I thought would be of particular interest to you as chemists.

INDUSTRIAL RESEARCH AT THE BUREAU OF STANDARDS

Read at the Washington Meeting, December 6, 1923

By P. H. BATES

There seems to be an impression that the Industrial Research of the Bureau of Standards is one of its later developments, arising from the somewhat recent awakening of industry to the need and value of research. However, such is not at all the case. The Bureau was founded and its work originally outlined upon the premises that in addition to the Standards of Measurement and Standard Constants, there are Standards of Quality, Performance and Practice. That the Bureau did not as actively pursue the work along certain of these lines as upon others was due to the necessity of deriving, first, the more fundamental Standards, and to the fact that the rapidly developing Bureau could not secure the more extensive funds for developing the personnel and the equipment required for these more "practical problems." But the year 1910 found the work concerning oils, paper, textiles, rubber, metallurgy, ceramics, cement, concrete, etc., well under way, and in some cases the experimental plants which feature the Bureau's method of approaching such problems in operation. By the time we were entering the late war, the industrial work had advanced to such a degree that much larger quarters were required immediately, and through special funds, the Northwest Building, housing the metallurgical work, the large Industrial Building, providing quarters for the major portion of the industrial work, and a building for the manufacture of optical glass at the Pittsburgh Branch of the Bureau were erected. The close of the war found the industrial work under way on a scale greater than it has been possible in some cases to continue it at the present time, owing to the postwar curtailment of appropriations.

You are undoubtedly interested in knowing how the Bureau selects the problems upon which it carries on Industrial Research and how the work is actually carried out. Such an interest would naturally arise because this type of work is usually associated with

producing interests, whereas the Bureau is a disinterested organization, or at least is concerned as much in the problems of the consumer as in those of the producer. As a matter of fact, the Bureau is the representative of a very large consumer—the United States Government—and it is in this latter respect that it first became interested in what may be grouped as Industrial Standards and Industrial Research.

Very early in its history it was asked by many of the purchasing agencies of the various Government Departments, to render an opinion as to the quality of a product, or as to the likelihood of a product giving adequate service if of a certain quality, or as to what properties a product should have for a definite service, or how the product would be affected by deviation from the usual requirements, or to draw up standards for a new product, or any of the other numerous questions that arise in the development and use of Standards. Frequently the question could be answered without any particular study but just as frequently the answer was not available because the product had not been studied along the indicated lines, even by the industry producing the commodities. Hence, one of the first reasons for the Bureau's taking up Industrial Research, was to inform itself in regard to other than the usual properties of various commodities. This reason still maintains, and may be well illustrated by the work which has about culminated in the development of standards for china ware (dishes of the so-called vitrified hotel ware).

This is a product which has been made and sold for years largely on the sole requirement that it appear white, be free from specks, blisters, etc., have a pleasing decoration and do not cost too much. One of the Government Departments (and the Government is a very large consumer of this ware in its army and navy barracks, aboard vessels of the navy and shipping board and in the various Government hospitals and homes) drew up specifications which in addition to the general clauses referring to size, etc., stated that the ware should be "fully vitrified." Among ensuing bidders were two, both of which claimed their ware was fully vitrified, but whose prices differed about 10 per cent, or approximately $10,000 on the total amount involved. The Bureau was asked to decide which of these best met the requirements, and naturally it asked in turn what was meant by "fully vitrified." No one concerned could give a definite reply, and particularly one that would involve "measurable terms."

According to the Bureau's interpretation, both manufacturers were meeting this indefinite requirement. But this did not serve to differentiate between the two samples and furthermore the Bureau had no measurable terms to apply. Hence, it started an investigation to see how the various hotel wares on the domestic market differed in the amount of water they could absorb under definite conditions, on the measured resistance required to cause fracture by a blow delivered on the edge or on the bottom, and to the relative resistance to abrasion. One of the first outstanding features of the results of its investigation was the very evident fact that in general domestic ware far excelled the imported ware. Possibly, however, the most vital result was the one which caused the domestic industry to look at their product in a new light. That is, that of service which it could render. The preliminary investigation was of such interest to the industry that it has entered into a very hearty cooperation with the Bureau in plant and laboratory studies of what strength and other properties their ware would have when produced under different conditions. Before it is completed, it is hoped to show how the various constituents used affect the quality of the ware and how this quality may be affected by different procedures in the manufacture.

The above example serves to illustrate one of the outstanding features in the Bureau's method of conducting its Industrial Research—that of cooperation with interests outside of the Bureau. There is not an Industrial Research of any magnitude under way at the Bureau at the present time, with which there is not connected an advisory committee representing outside interests and in the majority of cases these committees are representative of both the producing and consuming groups interested in the commodities and in many cases these committees are further augmented by consulting experts not attached to either of these groups. These committees assist in deciding what problems should be studied, the general methods of attack, discuss the data obtained and assist in drawing up and presenting the results for publication. Such a procedure insures the problem being of general interest to the whole industry concerned, and not such problems as more rightly should be conducted in the research laboratories of the individual interests in the industry.

This procedure, it must also be confessed, has been most eminently successful in bringing to the various industries, not only these phases of the Bureau's work in which they are particularly inter-

ested, but all the work of the Bureau. It is surprising to note how the members of these committees become acquainted with the various activities carried on, and the amount of time they will spend in consulting with the members of the Bureau staff on matters far distant from those being studied by the committee of which they are members, but which are most vital to them in their professional activities. These committees are also most potent in broadcasting the activities of the Bureau and bringing its reports directly to a most interested public which is frequently so placed as not to be able to get this direct contact otherwise. Hardly a week passes without two or three committees meeting at the Bureau in an advisory capacity. That these are just as helpful to the individuals attending and the groups interested as they are to the Bureau, can be appreciated from the fact that they receive no pecuniary remuneration from the Bureau. Yet, notwithstanding this, the meetings are fully attended and one of the difficulties encountered by the Bureau is keeping the total membership down to a good working number.

Another one of the features of the Bureau's handling of these Industrial Researches is the use of experimental plants of small or semi-commercial size for studying some of the phases of the problems. Thus may be cited; the foundry, rolling mill, rubber mill, textile mill, cement plant, glass plant, pottery, brick plant, enameling plant, etc. It has never been inferred that the results obtained in these experimental mills may be applied directly on a full plant scale or that there can be calculated directly from the data obtained in a small plant the efficiency or economy of a process applied on the large plant scale. For the purpose of establishing limits and defining the more restricted courses which the investigation should pursue when tried on the large scale, certain lines or fields may be explored in a small plant which would be entirely prohibited in the full plant scale on account of the cost. Furthermore, it is often desirable to know what properties a product should possess if the normal process of manufacture were altered, or if the amounts or kinds of constituents used in the raw materials were changed. Such changes are usually extremely costly in plant production and produce a commodity which may have no commercial value, although the data obtained in producing or testing it may be extremely valuable. The experimental plant is most valuable for such studies as these. It may be of interest to cite the fact that the present limit of five per cent of

magnesia in the standards for Portland cement was adopted as a result of the study of data obtained in producing high magnesia cements in the Bureau cement plant. In this particular case two series of Portland cements were manufactured in which the magnesia was increased from a content of about two per cent to that obtained by using dolomite instead of a high calcium limestone in the raw mix. Any commercial cement plant which would have made a cement of the magnesia content obtained in the majority of the cements so produced, would have been in the predicament of having a very large quantity of cement on hand, all of which was of a higher content than that then permitted by the existing standards. Yet but a relatively very small quantity was needed for the determination of the qualities of those high magnesia cements.

The policy of the Bureau of conducting its Industrial Research largely under the advisement of a group representative of the making, selling, buying and using interests, precludes the possibility of its taking up problems which would more properly be carried on in the research departments of either of these interests or by commercial laboratories subsidized by these. It is hardly likely that such a group would suggest problems which would be of more vital concern to any one of these interests than to the others. The major portion of a problem might consist in the manufacture of products under certain conditions or of certain compositions but this would be carried out largely for the purpose of finding out the properties of the product and what they could be expected to do under various conditions of of service. The Bureau is particularly careful to take up only those problems which are of general interest to all concerned, including the Government, and if the advising group should suggest questions of a type that more properly should be solved elsewhere, it does not hesitate so to inform them. It happens that the Bureau's close contact with the many trade associations, technical and scientific societies and research groups gives it a knowledge of the researches under way throughout the country, that is often not available to the members of the advising groups and hence puts it in a position to keep them better informed of the progress and the solution of problems in which they have not been so closely interested.

There have been indicated above the general fields covered in Industrial Research at the Bureau. It is clearly evident that nothing is being done for a number of important industries. This may be due

to several reasons. It may be that the problems would more properly come within the province of some of the other Government bureaus and hence should not be undertaken here; it also may be the unfortunate case that there is not a uniform demand on the part of all those who are interested in an industry for a research; or there may be such a diversity of ideas among those concerned as to what problems should be taken up, or how they should be pursued, that the whole matter is left in a more or less quiescent state, pending the crystallization of the ideas of those who are interested in the project. There are still some few further cases which it has not been possible to take up due to the exhaustion of the limited funds in those parts of the Bureau where the problem should be carried out, by work already under way. This deficiency has been met in a number of cases by the interested groups providing funds by means of which the personnel is made available at the Bureau, and the work carried out by this personnel under the direction of the Bureau's staff. This kind of assistance can be accepted only to a limited degree, as to space, equipment and the number of the staff available to supervise the work is limited.

The unfortunate condition exists at the present time which demands that any discussion of Industrial Research must devote some time to the dollars and cents returns of research. This is quite proper—within certain limits, but it is very questionable if this limit is not generally exceeded. The Bureau can cite some marvelously astounding statements of the returns of Industrial Research carried on here. The secretary of one association writes that the results of a bare year's work will mean the saving of $23,000,000 per annum to his industry. We may be inclined to question this figure, but it is no higher than amounts which have actually accrued from research. But Industrial Research no longer need be exploited or emphasized solely or to a major degree by these arguments, to even the so-called "hard-headed" business man (and it was most pleasing to have one of this very type call attention to the fact that in too many cases "hard-headed" and "bone-headed" are synonymous). Many of these are willing to pay for the research that will enable them to turn out even at an increased cost a more satisfactory product, and the consumer is willing to pay more for a product that he knows will give greater satisfaction. There is an increasing willingness on the part of all concerned to pay for research that will enable them to be

more fully acquainted with the qualities of the commodities that they are interested in and with no immediate returns in sight. There is so much research under way now by the hardest headed business men, with no financial returns in sight, now or in the distant future, that one is compelled to question this constant dwelling upon the pecuniary returns of research, in fact it is a debatable question whether there would not be more research now in hand, had not too many had their interest aroused solely on the basis of a return of all money put into it with a very substantial interest in addition. But this is enough of this phase of Industrial Research in this discussion.

There has arisen in the minds of some a questioning as to why the Bureau of Standards is carrying on Industrial Research. There is no better way to answer this than to refer to the functions of the Bureau as defined by its organic law, and as illustrated in the folded sheet inserted as a " frontispiece " in several of the last annual reports of the Director. According to this, the functions are " the development, construction, custody and maintenance of reference and working standards, and their intercomparison, improvement and application in science, engineering, industry and commerce." When it is borne in mind that in addition to the two commonly thought-of standards—Standards of Measurement and Standard Constants—there are the very important standards indicated by law as those with which the Bureau should concern itself, and mentioned in the first paragraph of this paper, namely, Quality, Performance and Practice, that there should be no further doubt as to why Industrial Research forms one of the most important functions of the Bureau.

ATOMIC PHYSICS AND ITS RELATION TO CHEMICAL ENGINEERING

By PAUL D. FOOTE

Read at the Washington Meeting, December 6, 1923

This paper to a considerable extent assumes the rôle of a puzzle picture, in that the reader is asked to find the relation, the presence of which is suggested by the title. On the other hand, even the most "practical" engineer will affirm that the future of chemistry lies in a more thorough knowledge of the structure of atoms and of the forces effective in the production of chemical combinations, and that, further, the remarkable progress of the past decade in applied science has been possible largely because we are learning to deal familiarly with the component parts of a complicated atom.

Who would have dared to prophesy the commercializing of the electron, and that even now the operation of certain industries should be attendant on our understanding the caprices of this minute quantity of electricity? The electron which is projected from a glowing filament and thus makes possible long-distant telephonic communication either with or without wires, the electron which generates the x-ray in the Coolidge tube or produces illumination in the arc lamp, this same electron is directly responsible for all reactions forming the basis of the chemical industry. Of course, in a general way, every physical and chemical property involves relations between atoms and electrons, and in the last analysis the building of a table by a cabinet-maker is a problem in electronics. However, the complete solution, even if possible, of such an involved problem at the present state of the art would scarcely lead to the production of better tables. There are, on the other hand, numerous processes where an understanding of the microscopic structure of matter is essential and where the entire mode of procedure depends upon our conception of the transition or motion of an electron. In many cases where we have no satisfactory theory, development of the work is effectually blocked. The fixation of nitrogen, active nitrogen, photochemical synthesis and decomposition, photo- and photographic chemistry, electrochemistry,

the chemistry of gaseous reaction, reaction at high temperatures, dissociation, illuminants involving oxidation processes, catalytic agents, these and countless others involve problems where real progress is conditioned by our knowledge of the changes which may take place in the interior of an atom. We shall, therefore, consider some of the recent developments in the interpretation of atomic structure.

The atomic number Z is the ordinal number of an element in the periodic classification, 1 for hydrogen, 2 for helium, 11 for sodium, and 92 for uranium. An atom consists of a nuclear positive charge Ze surrounded by Z planetary electrons each of negative charge e. The nucleus or sun in this planetary system is a very complicated structure, slight alterations of which give rise to isotopes and to radioactive disintegration. Although the nucleus is highly complex it is extremely small compared to the size of an atom, as may be shown in experiments upon the scattering of α-particles from a radioactive source when these collide with atoms of the material through which they pass. Yet the mass of an atom is almost entirely concentrated in the nucleus, that of the planetary electrons being practically negligible. On account of the large relative mass of the nucleus and its minute size, the motions of the planetary electrons are closely determined, solely by the nuclear charge Ze, which may be considered as a point charge, and by the perturbing influences of the other revolving electrons.

Although an atom is accordingly a complicated planetary system, it possesses certain unique properties which are not exhibited by ordinary planetary systems acting under gravitational forces. The shapes of the orbits of the planets in a gravitational system depend upon the physical conditions effective in the original formation of the universe. The total energy of such a system depends upon its past history. Our own group of planets could be arranged in an infinite variety of forms, equally stable, and in general, if a large number of solar systems existed, each with component parts exactly like our own, no two would be similar nor would any two possess the same energy. If a sufficiently large comet or meteor approached this earth, our year would be altered and the total energy of the solar system would be permanently changed. An infinitely and continuously variable alteration in the energy could occur, depending upon the disturbing forces.

In contrast to this, all the atoms of a given element in the normal

state possess the same energy and presumably therefore the motions of the planets or electrons are similar. If a comet, speeding through the interior of an atom, which is a more open structure than our solar universe, collides with one of the revolving electrons, the energy of the system is increased, but only by certain discrete amounts. We may verify this accurately in the laboratory by an electrical method in which the energy of an electron-comet is measured before and after its collision with an atom. Always it is found that the comet can communicate only certain discrete amounts of energy to the atom. For example, an atom of mercury may abstract 7.74×10^{-12} or 10.62×10^{-12} ergs of energy from the comet but it can not absorb an intermediate value; the comet retains any excess energy when it leaves the system. Reckoned in more familiar units these energies amount to 112 and 154 kg. cal. per g. mol. By the same electrical methods we are able to determine how much work the comet must do in order completely to eject an electron from an atom. This, of course, depends upon the atom and upon what electron in the atom is ejected. Some of the electrons are very firmly bound because they revolve closely around the nucleus. Other electrons in the outer portions of the atom are comparatively easily removed. The electrons which are relatively loosely bound are those which are effective in chemical reactions, the valence electrons. But no matter what electron is ejected, it always requires a definite amount of work, and the same work for the corresponding electron in every atom of the same element.

If the atom absorbs a certain quantity of energy from the comet, which is *insufficient* to remove an electron and produce ionization, it temporarily exists in a so-called excited state, the duration of which may be one hundred millionth of a second. The absorbed energy is then emitted as monochromatic radiation and the atom settles down to its original condition with an energy characteristic of the normal state. It always requires just the same amount of energy to put any atom of the same element into any particular excited state, and the emitted monochromatic radiation or spectral line always possesses the same wave-length within the accuracy of measurement, which in some cases is nearly one part in ten million. Such general conclusions are true for all spectral lines, and indeed the entire subject of spectroscopy exists only because of the peculiar fact that the planetary systems of the atoms belonging to a given atomic species are similar,

whether the radiating atoms be in the laboratory or on a distant star.

The ordinary dynamics is not capable of interpreting these various atomic phenomena. From purely classical considerations we should be forced to deny the existence of line spectra. It is necessary to introduce the conceptions of the quantum theory which have been found essential in the interpretation of black-body radiation, specific heat, photoelectric effect, photochemical reactions, and other phenomena of Nature. Bohr [1] makes two general postulates, one relating to the stability of atoms and the other to the existence of sharp spectral lines. The first postulate assumes the possibility of a series of discrete stationary states of the atom of such stability that any lasting alteration of the system consists in a complete transition between two stationary states. The second postulate assumes that when an atom undergoes such a transition, a quantum of radiation, having the energy $hc\nu$ equal to the differences in energies of the two states, is emitted or absorbed, where h is Planck's universal constant of action, c the velocity of light, and ν the wave number of the radiation.[2]

In the empirical development of spectral series [3] it is found that the wave number of any line may be represented as the difference of pairs of constantly recurring wave numbers or variable terms. Systematic groups of wave numbers may be tabulated for an element such that their differences, taking two at a time, give the wave numbers of all the lines, the element is capable of emitting. Since by Bohr's second postulate hc times the wave number of the emitted

[1] Bohr, "The Theory of Spectra and Atomic Constitution," 1922, Cambridge University Press. "Line Spectra and Atomic Structure," *Ann. d. Phys., 71,* 228–88, 1923. Bohr and Coster, "X-ray Spectra and the Periodic System of the Elements," *Z. Physik, 12,* 341–74, 1923.

[2] Wave number is defined as the reciprocal of the wave-length of the spectral line in centimeters in vacuum; $h = 6.554 \cdot 10^{-27}$ erg sec.

[3] The simplest type of series consists of a group of related lines which gradually and regularly become closer together as the wave-length decreases. The limiting wave-length which the lines approach is called the limit of the series. Thus, in the Balmer series of hydrogen, the first line lies in the red, the second line in the green, the third in the blue, and the following twenty-six known lines extend to $\lambda = 3661$ A in the ultraviolet. The limit which these lines approach lies a few Angstrom units further to the shorter wave-lengths. In general, a series is more complicated, consisting of groups of lines instead of singlets. Thus, we have series of doublets in the alkalis, series of triplets in the alkali earths, and series of multiplets for certain other elements.

radiation is equal to the difference of the energies of the atom in two stationary states, and since empirically we find this wave number always equal to the differences of two variable terms, we may associate each empirically determined variable term with the energy of the atom in a particular stationary state. That is, hc times the wave number of a variable term gives directly the energy of the atom in some stationary state. These variable terms are Nature's solution of the dynamics of the atom, which is much more complete than is furnished by the meager and difficult experiments on the loss in energy suffered by an electron-comet upon collision with an atom.

The hydrogen atom is a readily solvable problem of two bodies, a nucleus and a single electron. Knowing, from the spectroscopic data, the energies of the various states which the atom can assume, the dimensions and shapes of the orbits upon which the electron revolves may be determined and certain general principles may be derived which are useful in the consideration of heavier and more complicated atoms. The various possible elliptical and circular orbits of the electron in the hydrogen atom may be completely specified by two integers n and k, written for convenience n_k, where n is called the chief quantum number and k the azimuthal quantum number. When $n = k$ we have a circle and for k less than n, ellipses, the eccentricity of which increases the smaller the ratio k/n as shown in Fig. 1. Groups of orbits having the same value of n are called n-quanta orbits, while any specific orbit is referred to as an n_k-orbit, with the proper values of n and k.

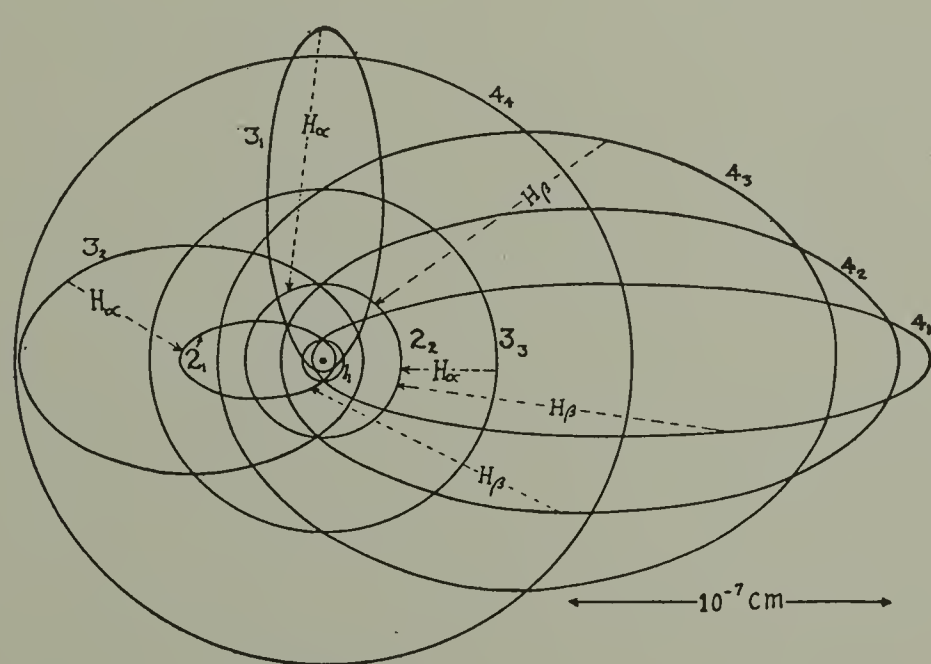


FIG. 1. Possible electron orbits in hydrogen, up to total quantum number 4.

In the normal state an atom assumes the most stable configuration where the energy has its smallest value. The electron in the normal hydrogen atom revolves on a circular 1_1 orbit having a radius $5.3 \cdot 10^{-9}$ cm. The work required to remove this electron, leaving the atom as a positive ion, is known as the ionization potential and the value computed from the dynamics of the model agrees precisely with that determined in our laboratory by the electrical method described. Transitions of the electron between different orbits accounts for all the lines emitted by the hydrogen atom, as indeed they must, because these lines were used in determining the dynamics of the model. There are, however, no phenomena of physics or chemistry which are inconsistent with this "spectroscopic" atom and many facts predicted by the theory have been since verified experimentally.

Bohr considers the building of the heavier atoms by a synthetic process in which one starts with simply the nucleus of charge Ze and feeds in Z electrons one after the other until the complete atom is formed. If the nuclei themselves were stable, such a process could take place in a star which is slowly cooling from an extremely high temperature—a temperature sufficiently great to produce complete dissociation or ionization of an atom, in accordance with the Nernst reaction-isochore. Each successively added electron revolves in its own orbit which is determined, as with hydrogen, by the two integers n_k. In general, no two electrons occupy the same orbit and the orbits of different electrons are not coplanar, so that a three-dimensional space configuration is obtained.

The binding of the first electron to any nucleus gives rise to a spectrum exactly similar to that of the hydrogen atom, except that it is displaced farther to the shorter wave lengths the larger the value of Z. The stages in the capture of the last electron are shown by the ordinary arc spectrum of the element, the spectrum obtained when the atom as a whole is neutral. During the binding of the next to the last electron the atom possesses a total positive charge of one unit and the "first" spark spectrum is emitted in the various stages of the process. Spark spectra of higher order, arising in multiply ionized atoms, are known for a few elements. For example, the spectrum of silicon which has lost three electrons has been recently correlated in series by Fowler, and we thus have direct information in regard to the binding of the 11th electron to the silicon nucleus with its positive charge of 14 units.

The most serious difficulty in the development of Bohr's theory of atom building is the fact that the spark spectra, especially of the higher orders, are at present little known. For this reason there exist wide gaps in the experimental evidence for the successive capture of electrons, especially in a heavy element, which must be bridged by assumptions in regard to what the spectrum should be were it known, and by comparison with the stages in the building of atoms where the spectral data are more complete. These difficulties are quite serious in the determination of the outer structure of an atom, in fixing the type of orbits occupied by the loosely bound electrons which are effective in chemical reactions. The positions assigned to the closely bound electrons in a heavy atom, electrons which play no part whatever in chemical phenomena, may be satisfactorily determined by experimental data on x-rays. For example, measurements of x-ray absorption limits give directly the work required to remove the various electrons from the inner shells of the atom.

Stages in the capture of the first electron by the helium nucleus, $Z = 2$, are evidenced by the well-known spark spectrum, resembling hydrogen, and the electron is finally bound in a 1_1 circular orbit, with half the radius of the hydrogen atom because the nuclear charge is twice as great. The second electron also finally occupies a 1_1 orbit, while the relative orientation of the orbits has not been satisfactorily determined. Bohr believes the atom resembles the form shown in Fig. 2, but the model gives too low a value for the work required to

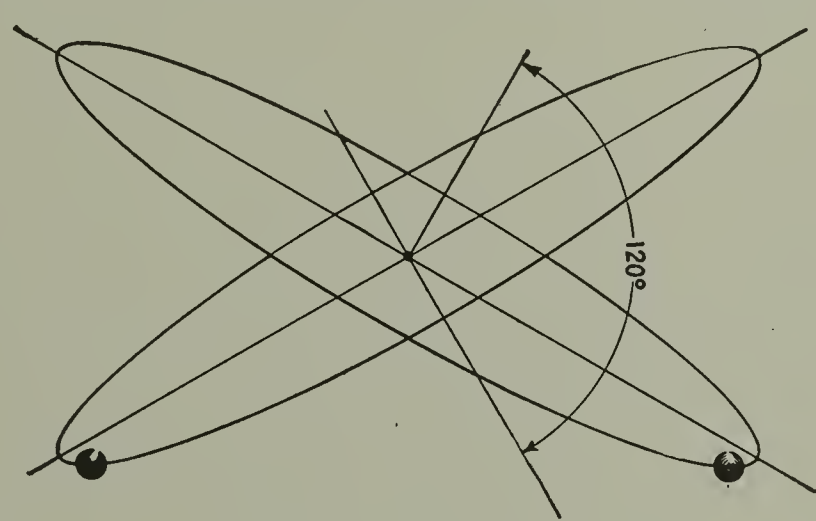


FIG. 2. Helium (2).

remove one of the electrons. Whatever be the detailed nature of the orbits, Bohr considers that this symmetrical arrangement is characteristic of the position occupied by the first two electrons in every

atom. It represents the K-shell and disturbance of these electrons in heavy atoms gives rise to the well-known K-radiation of x-rays.

The third electron in the formation of lithium occupies a 2_1 elliptical orbit as may be deduced from a consideration of the highest wave number in the arc spectrum, the limit of the series of absorption lines obtained when a column of lithium vapor is viewed against a continuous back-ground. The limit of an absorption series in an optical spectrum always determines accurately the energy required to remove a loosely bound electron. For lithium this is less than one-half that necessary to remove the electron from the hydrogen atom or about one-fourth that required to remove either electron from the helium atom. The relative ease with which this outer electron may be taken away from the lithium atom accounts for its electropositiveness, and the presence of a *single* readily removable electron shows that the element is monovalent. It requires about nine times as much work to take an inner electron away from lithium as that necessary to remove the valence electron. Expressed in kilogram calories per mol, the work required to remove the valence electron from lithium is illustrated by the following table in which data on the other alkalis are given for comparison. These values are obtained from spectroscopic observations, but they have been directly confirmed by electrical experiments in our laboratory.[4]

TABLE I

WORK REQUIRED TO REMOVE VALENCE ELECTRONS FROM 1 GRAM MOL

Element.	Kilogram Calories Per Gram Mol.
Lithium	123.8
Sodium	118.0
Potassium	99.7
Rubidium	95.9
Cæsium	89.4

The model[5] of the lithium atom as derived from spectroscopic data is shown in Fig. 3. On account of the perturbing effect of the

[4] *Cf.* Foote and Mohler, "The Origin of Spectra," Chemical Catalog Co., New York.

[5] This illustration and those for the heavier atoms have been taken from *Die Naturwissenschaften,* No. 27, July 6, 1923, a special issue of nearly one hundred pages on various phases of Bohr's theory. Although the actual atoms are space configurations, no attempt has been made to show them in perspective. The diagrams are therefore merely schematic.

two inner electrons, the orbit of the valence electron is a precessing ellipse, as is true for all the orbits in complicated atoms.

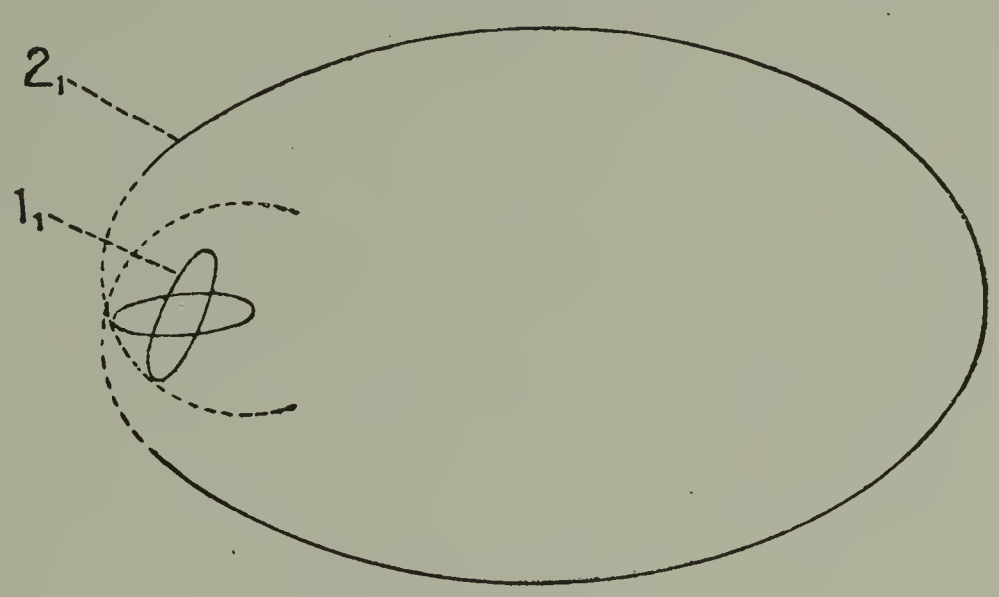


FIG. 3. Lithium (3).

From an analysis of the spectra of the various atoms Bohr is thus able to assign quantum numbers to the planetary electrons of a large majority of the elements as shown in Table II. We shall not consider the numerous details through which such assignments have been made, but will point out several interesting features of a general nature. Electrons are added in higher quantum orbits, or shells in the Lewis-Langmuir-Bury theory, with no striking irregularities un-

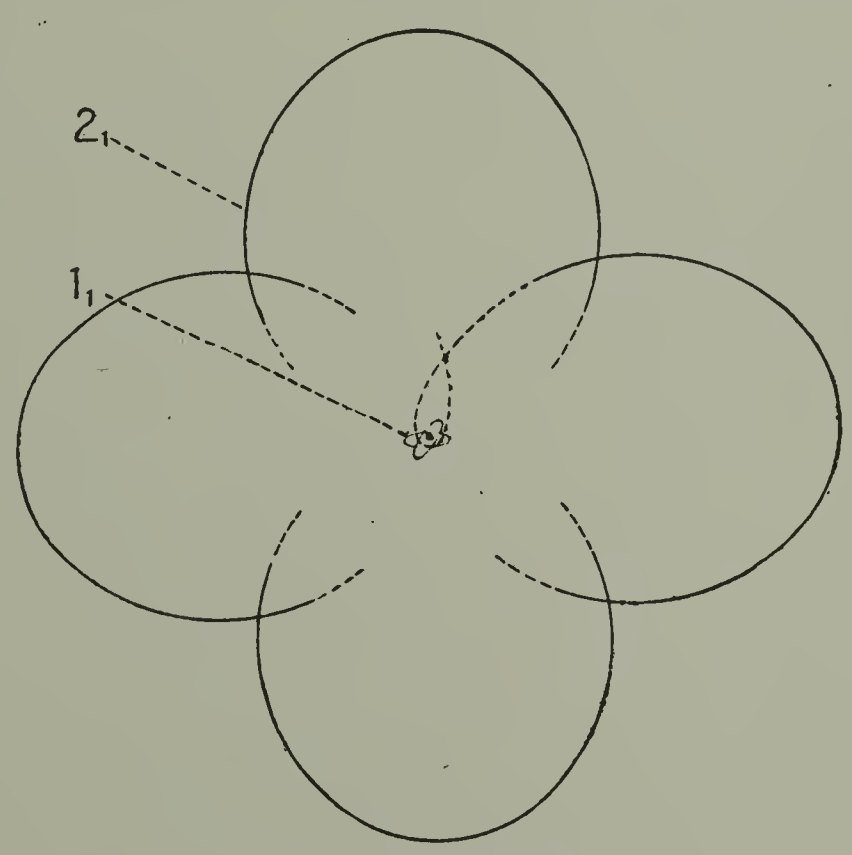


FIG. 4. Carbon (6).

til scandium is reached. Carbon presents the symmetrical tetrahedral structure shown in Fig. 4, neon a symmetrical configuration with eight *outer* electrons revolving in 2_1 and 2_2 orbits, Fig. 5.

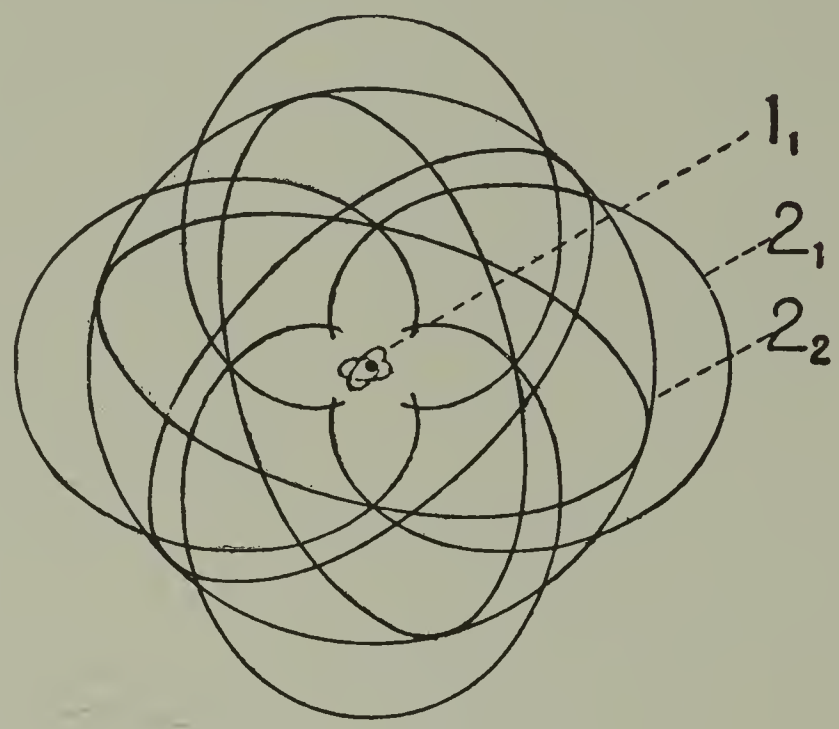


FIG. 5. Neon (10).

The third period begins with sodium (11). The under structure of this element resembles that of neon to which the eleventh electron, the valence electron, is added in a 3_1 elliptical orbit, Fig. 6. The

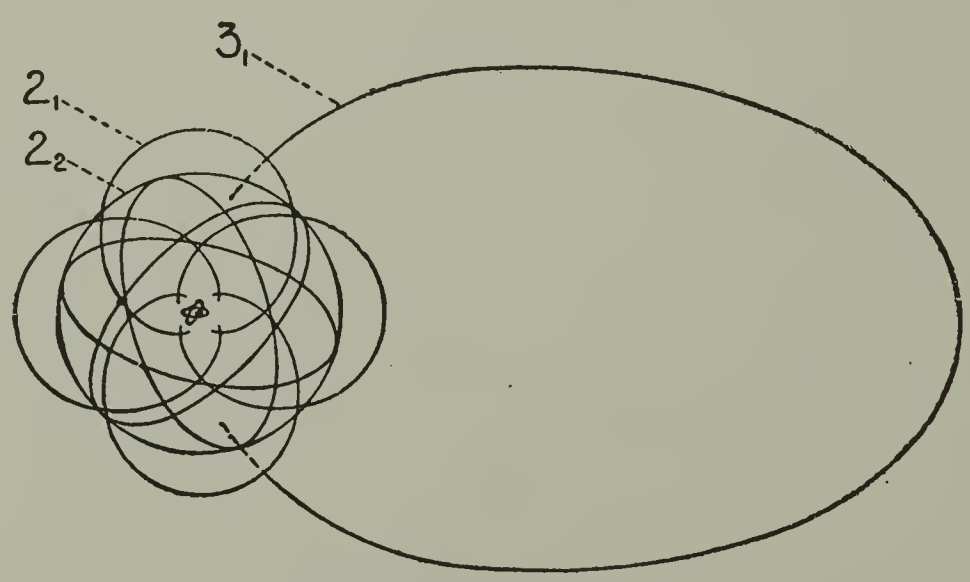


FIG. 6. Sodium (11).

firmness with which this electron is bound is even less than that for the valence electron in lithium as shown in Table I. Electrons are now added in 3-quanta orbits, and argon (18) presents an external structure similar to that of neon (10) in that it possesses an outer

group of eight electrons, four in 3_1 orbits and four in 3_2 orbits, as illustrated by Fig. 7. With the neon understructure, the valence electron in potassium (19) revolves in a 4_1 orbit, the exterior of the

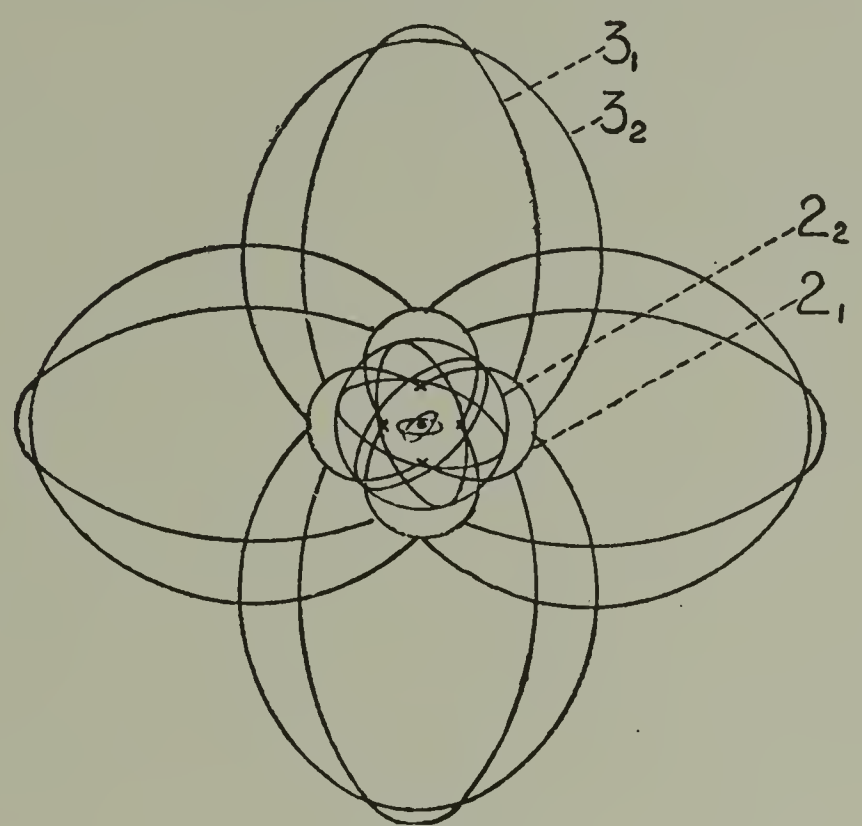


Fig. 7. Argon (18).

model resembling that of sodium. Calcium (20) has two valence electrons in 4_1 orbits with an outer structure like radium (88), Fig. 11.

One notes that the orbits of the valence or outer electrons penetrate the interior regions of the atom, and at perihelion the valence electron may approach nearer to the nucleus than any of the electrons previously bound in orbits of greater energy. Here it is acted upon by practically the entire force exerted by the nucleus of charge Ze, whereas in the outer portion of its orbit the attraction of the nucleus is screened by the other electrons. At large distances the combined effect of the nucleus and surrounding electrons on a single valence electron approaches that of a single positive charge. This characteristic interpenetration of orbits produces a large effect upon the work required to remove an electron from any particular orbit and is shown clearly by the great difference in the spectra of atoms when compared to that of hydrogen. Were it not for the penetration of the valence electron of cæsium into the inner structure, for a small portion of its orbit, it would require only 8.7 kilogram calories per

TABLE II

Number of Electrons in Different n_k Orbits

Period	Z	1_1	2_1 2_2	3_1 3_2 3_3	4_1 4_2 4_3 4_4	5_1 5_2 5_3 5_4 5_5	6_1 6_2 6_3 6_4 6_5 6	7_1 7_2
1	1 H	1						
	2 He							
2	3 Li	2	1					
	4 Be	2	2					
	5 B	2	2 (1)					
	– –	–	– –					
	10 Ne	2	4 4					
3	11 Na	2	4 4	1				
	12 Mg	2	4 4	2				
	13 Al	2	4 4	2 1				
	– –	–	– –	– –				
	18 A	2	4 4	4 4				
4	19 K	2	4 4	4 4	1			
	20 Ca	2	4 4	4 4	2			
	21 Sc	2	4 4	4 4 1	(2)			
	22 Ti	2	4 4	4 4 2	(2)			
	– –	–	– –	– – –	–			
	29 Cu	2	4 4	6 6 6	1			
	30 Zn	2	4 4	6 6 6	2			
	31 Ga	2	4 4	6 6 6	2 1			
	– –	–	– –	– – –	– –			
	36 Kr	2	4 4	6 6 6	4 4			
5	37 Rb	2	4 4	6 6 6	4 4	1		
	38 Sr	2	4 4	6 6 6	4 4	2		
	39 Y	2	4 4	6 6 6	4 4 1	(2)		
	40 Zr	2	4 4	6 6 6	4 4 2	(2)		
	– –	–	– –	– – –	– – –	–		
	47 Ag	2	4 4	6 6 6	6 6 6	1		
	48 Cd	2	4 4	6 6 6	6 6 6	2		
	49 In	2	4 4	6 6 6	6 6 6	2 1		
	– –	–	– –	– – –	– – –	– –		
	54 Xe	2	4 4	6 6 6	6 6 6	4 4		
6	55 Cs	2	4 4	6 6 6	6 6 6	4 4	1	
	56 Ba	2	4 4	6 6 6	6 6 6	4 4	2	
	57 La	2	4 4	6 6 6	6 6 6	4 4 1	(2)	
	58 Ce	2	4 4	6 6 6	6 6 6 1	4 4 1	(2)	
	59 Pr	2	4 4	6 6 6	6 6 6 2	4 4 1	(2)	
	– –	–	– –	– – –	– – – –	– – –	–	
	71 Lu	2	4 4	6 6 6	8 8 8 8	4 4 1	(2)	
	72 Hf	2	4 4	6 6 6	8 8 8 8	4 4 2	(2)	
	– –	–	– –	– – –	– – – –	– – –	–	
	79 Au	2	4 4	6 6 6	8 8 8 8	6 6 6	1	
	80 Hg	2	4 4	6 6 6	8 8 8 8	6 6 6	2	
	81 Tl	2	4 4	6 6 6	8 8 8 8	6 6 6	2 1	
	– –	–	– –	– – –	– – – –	– – –		
	86 Nt	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4	
7	87 –	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4	1
	88 Ra	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4	2
	89 Ac	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4 1	(2)
	90 Th	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4 2	(2)
	– –	–	– –	– – –	– – – –	– – –	– – –	–
	118 (?)	2	4 4	6 6 6	8 8 8 8	8 8 8 8	6 6 6	4 4

mol to remove this electron, or less than one-tenth the actual amount of work shown in Table I.

With the 21st element, scandium, a further development of the underlying 3-quanta orbits begins, and the 19th electron which in potassium and calcium revolves in a 4_1 orbit, in scandium (21) must be assigned to a 3_3 orbit. The spectroscopic evidence for this is afforded by a comparison of terms in the arc spectrum of potassium and the first spark spectrum of calcium, and extrapolating such relations to the as yet unclassified second spark spectrum of scandium. A transition stage is thus initiated through which the underlying 3-quanta group of orbits is developing from two groups of four to three groups of six, with minor changes in the outer shell containing the 4-quanta orbits. In this fourth period of the periodic table we have for the first time successive elements of similar chemical behavior, iron, cobalt, and nickel, which fact is attributable to the development of the under structure while the outer structure effective in chemical reactions remains substantially unchanged. With copper (29), Fig. 8, the transition stage is closed and the last electron re-

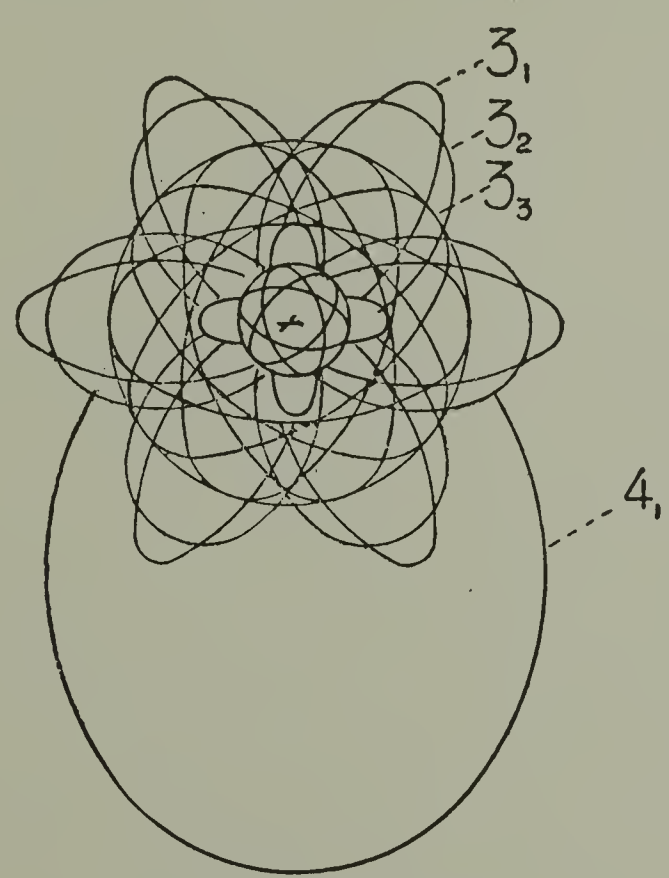


Fig. 8. Copper (29).

volves in a 4_1 orbit, like potassium. However, the binding of the next to the last electron is not nearly so firm as for potassium, as is evidenced by the ease with which spark lines of copper are excited,

so that an electron in a 3_3 orbit may be readily removed. This accounts for the appearance of copper in both the cupric and cuprous forms. Succeeding elements in this period are built by the addition of electrons in the 4-quanta shell until the period is closed with the symmetrical configuration for krypton (36), which has an outer group of eight electrons, four each in 4_1 and 4_2 orbits, as shown by Fig. 9.

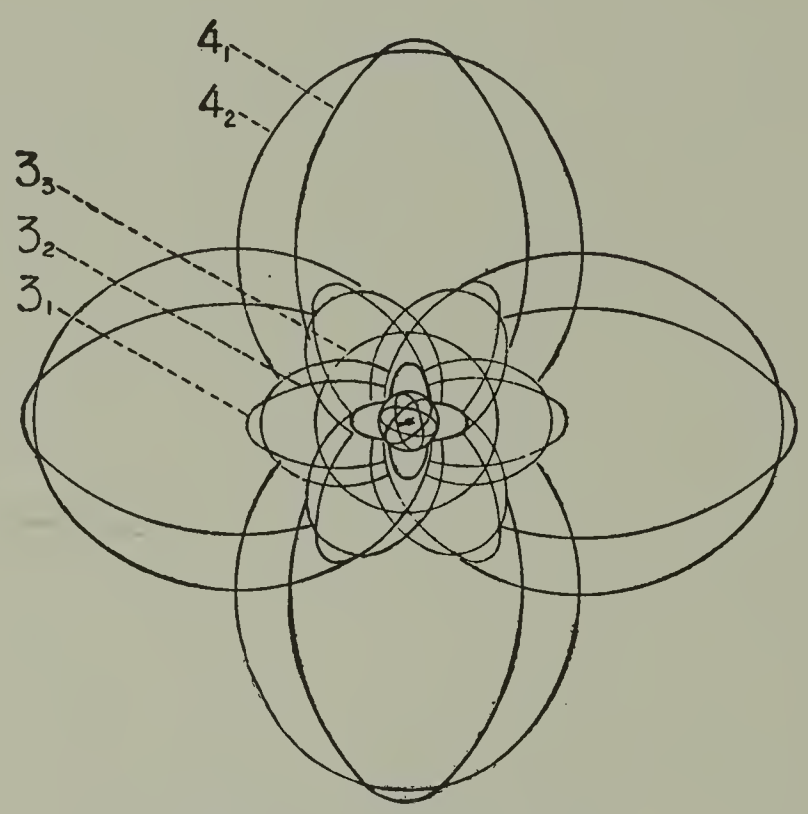


Fig. 9. Krypton (36).

The 5th period involves transitions quite similar to those in the preceding period. The valence electron for rubidium revolves in a 5_1 orbit, but preceding silver we have a stage where the 4-quanta orbits in the underlying shell are developing from three groups of four to three groups of six, which accounts for the similarity of ruthenium, rhodium, and palladium. The period is closed with the rare gas xenon, Fig. 10, again a symmetrical structure with an outer group of eight electrons.

The sixth period initiates the building of 6-quanta orbits. The last added or valence electron in cæsium occupies a 6_1 orbit; the two valence electrons of barium also revolve in 6_1 orbits. Beginning with lanthanum the underlying 5-quanta shell is developing, and with the next element, cerium, the first step toward the *completion* of the 4-quanta shell is initiated. Transitions in such a deep-lying level can produce but small variation as far as the chemical properties are

concerned, and this group of elements where there is a development from three groups of six to four groups of eight 4-quanta orbits is evidenced in the periodic table by the rare earths. Bohr's theory would predict that 14 elements should follow lanthanum having about the same general chemical properties and belonging with

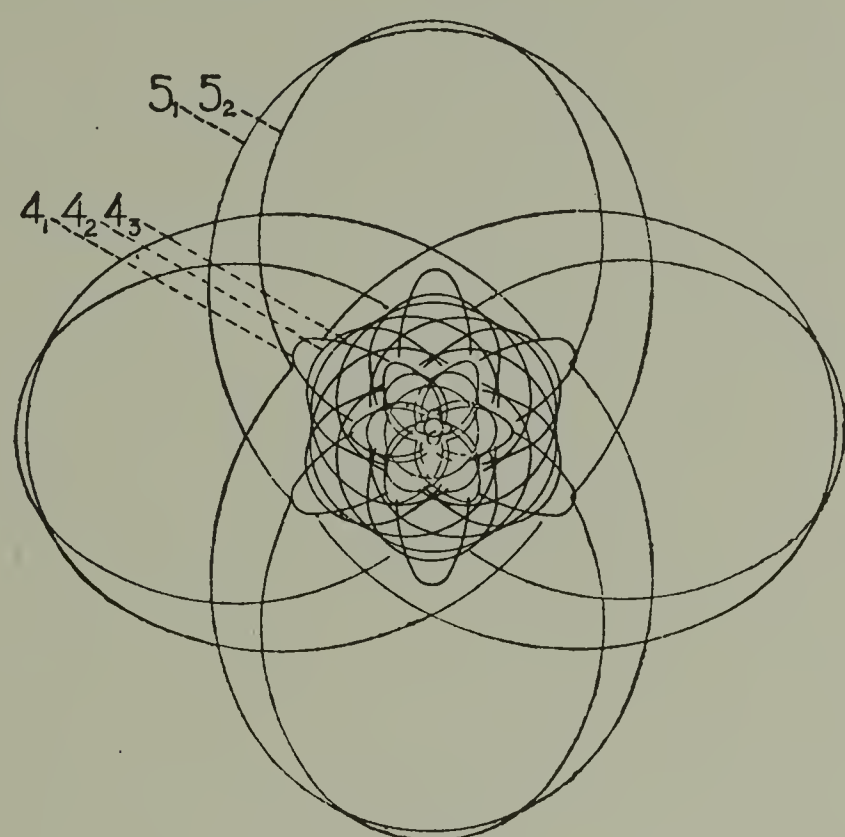


Fig. 10. Xenon (54).

lanthanum to the third group of the periodic table. With the last element in this group, lutecium, of atomic number 71, the underlying 4-quanta orbits are completely filled. In the building of the next element, the 72d electron must revolve in an outer orbit and hence we should expect a marked change in the chemical properties, and the 72d element should belong to Group IV, thus resembling zirconium.

In fact if this, until recently undiscovered, element had proven to be a rare earth with the valence 3, as was frequently maintained, a rather serious difficulty for Bohr's theory would have arisen. The 73d element, tantalum, has a valence of 5 and accordingly possesses 5 comparatively loosely bound electrons in the outer shell. Thus, if there were 5 loosely bound electrons in the 73d element and only 3 loosely bound electrons in the 72d element, one of the closely bound electrons, the 69th, in the building of element 72 would be changed to a loosely bound electron in element 73. But the theory requires

that the 69th (and any particular) electron be bound more firmly in every succeeding atom because of the increase in the nuclear charge. The 69th and following electrons in the 72d element should be therefore loosely bound and the element should possess a valence of 4.

Bury [6] was led independently to this conclusion on the basis of symmetry in the static atom so that the prediction of the chemical properties of the missing element possibly may not be uniquely credited to the Bohr theory, as is sometimes stated. However, Bohr's work gave stimulus to investigation with the result that Coster and Hevesy,[7] by means of x-ray analysis, found the 72d element associated with zirconium-bearing minerals as predicted. The new element has been named hafnium (Hf) in honor of Bohr's city Copenhagen, and large quantities of the material have been isolated by Hevesy. In fact, it is astonishing that the discovery of this element has been so long delayed, for Hevesy estimates that it represents 1/100,000 of the earth's crust and is therefore more plentiful than lead, tin, and many other metals of commerce. No doubt, some use will be found for this new element and its refinement *may* (?) eventually involve as great engineering problems as have been encountered in the comparatively recent developments associated with tungsten, vanadium, and titanium.

The building of the elements in the sixth period now continues in much the same manner as in the fifth period. There is a transition in which the 5-quanta shell changes from groups of four electrons to three groups of six, the development being completed with the 79th element gold. Preceding gold we have the three chemically similar elements, osmium, iridium, and platinum, where the essential changes in the electron configuration occur in the underlying 5-quanta shell. Electrons are then added in 6-quanta orbits and the period is closed with niton 86, the outer structure of which is characteristic of the rare gases.

The seventh period begins with the unknown alkali of atomic number 87 which should have a single valence electron in a 7_1 orbit,

[6] Bury, *J. Am. Chem. Soc.*, *43*, 1602, 1921. Kossel made similar predictions, cf. *Ann. d. Phys.*, *49*, 247, 1916, but contradicted them in the same paper. Bohr was the first to give a reason why the 71st element should be the last rare earth, and this at a time when existing X-ray data on "celtium" pointed to the contrary. A discussion of the celtium-hafnium controversy is beyond the scope of the present article.

[7] Coster and Hevesy, *Nature*, *111*, 79, 1923; Hevesy, *Ber.*, *56*, 1503, 1923.

followed by radium with two valence electrons in similar orbits, Fig. 11. The period is not complete as no element of atomic number greater than 92, uranium, is known. It is possible to continue Bohr's

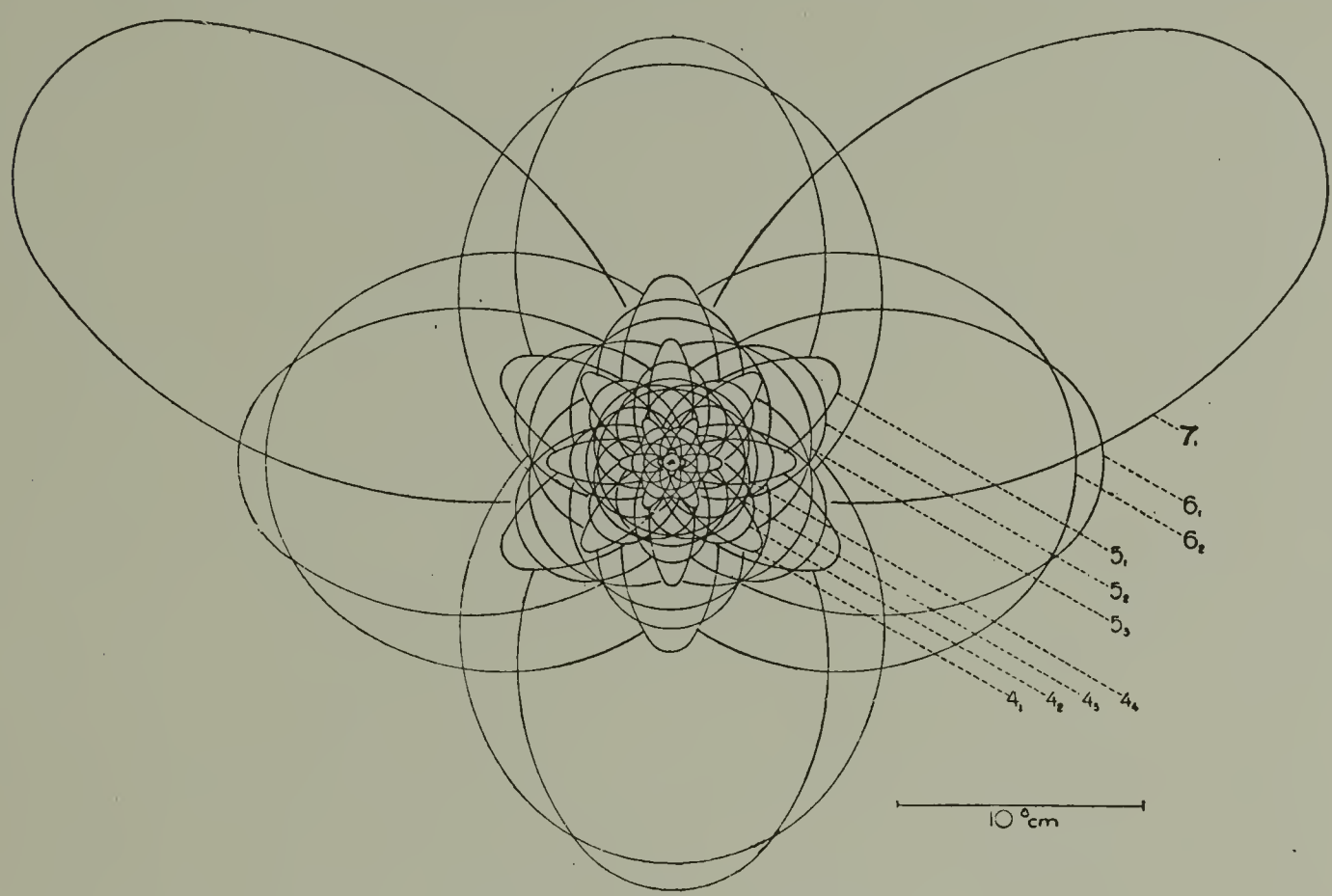


FIG. 11. Radium (88).

reasoning, by analogy to the building of the elements in the sixth period, and thereby arrive at a hypothetical atom of atomic number 118, a rare gas closing the 7th period. The apparent non-existence of elements heavier than uranium may be ascribed to the instability of the nuclei rather than to the impossibility of such a planetary system of electrons, an instability which is indicated by the nuclear disintegrations associated with the radioactive properties of elements of high nuclear charge.

This hasty and inadequate sketch of Bohr's theory of atomic structure at first sight appears to conflict seriously with the conceptions underlying the cubical atom of Lewis, Langmuir, and Bury. Actually, however, one may consider the dynamical atom as a generalization of the static atom and many of the desirable features of the latter have been utilized. For example, the grouping of the electrons resulting from Bury's modification of Langmuir's postulates is practically identical with that independently assumed by Bohr. The

extreme portions of the eight outer electron-orbits in the rare gas configuration are supposed to have a symmetrical distribution, and to some extent no doubt the effect of these electrons upon other atoms may be replaced by that of a fixed charge in each extended orbit or corner of a cube. The success of the static atom in interpreting many chemical phenomena would indicate that such a simple picture of the atom approximates the truth for certain purposes. Analogously, we employ the billiard-ball atom in the kinetic theory of gases, recognizing that the usefulness of the kinetic theory is no argument for the resemblance of an atom, in its finer structure, to a billiard ball. Nor are the verifications of the numerous predictions arising in the static theory evidence for the correctness of such simple models. Even Mendeleef with no idea of an atomic model was able to predict the properties of elements at that time unknown, for example, gallium, germanium, and indium.

An atom is necessarily much more complicated than a rigid cube or sphere and many of the newer problems in physics and in chemistry require that this finer-grained structure be given consideration. Bohr's attempt to do this chiefly by the use of spectroscopic data has led to atomic models more satisfactory for chemistry than the static models, and at the same time a means is afforded for the correlation of varied physical and physico-chemical phenomena. The extension of Bohr's theory to molecular models will be possible through consideration of band spectra, a subject now in the initial stage of development. Possibly the fruitful conception of "electron-sharing" will be intimately connected with the rotation of one atom or part of one atom about another in the molecule.

No doubt the Bohr theory will be eventually superceded by other hypotheses which prove still more satisfactory, or will be so modified that it will have lost its identity—this is the fate of every theory. Its success at present is due to the vast number of different phenomena which it is able to correlate by means of very few and simply stated postulates. The value of such correlation lies in new prediction and discovery to which it inevitably leads—and has already led.

Bureau of Standards,
Washington, D. C.

Discussion

Mr. Coggeshall: I understand that if one electron is ejected from the atom, a positive ion results. How are negative ions obtained?

Dr. Foote: A negative atom-ion is produced when the neutral atom captures an extra electron. The symmetrical configurations representing the rare gases are extremely stable, as is evident from the lack of ordinary compounds with such gases. (Such compounds may be formed under electrical stimulation, but this is a different problem.) Now from the direct evidence of valence, on the basis of either the static or kinetic models, there is a tendency for the outer group or shell of electrons in any atom to assume the stable rare gas configuration. The chlorine atom exerts an attractive force upon an electron, tending to become a negative ion with an outer structure similar to argon. Likewise the sulphur atom is able to draw two electrons into its outer shell. This peculiarity that the negative ion represents a more stable configuration than the atom itself is not so surprising. For example, a static model is readily devised in which four negative charges, grouped symmetrically about a nucleus with a positive charge of three, represent a more stable structure than a symmetrical group of three electrons about a positive charge of three. The fact that the halogen atoms, for example, are less stable than their negative ions means that energy is given out when the atom becomes an ion. For chlorine this amounts to about 116 kg. cal. per g. atom. There are three different methods for measuring this, as discussed on page 179 in "The Origin of Spectra," Chemical Catalog Co. If a gram atom of sulphur atoms become doubly charged, negatively, energy amounting to 45 kg. cal. is released. With the halogens, and probably with the other elements possessing electron affinity, this energy appears as radiation in the form of a continuous spectrum terminating sharply on the *long* wave-length side, this limit defining the energy of the reaction.

Mr. Coggeshall: What, then, is the difference between a chlorine ion and the argon atom?

Dr. Foote: The nuclear charge is 18 units with argon and only 17 units with chlorine. This might alter slightly the relative sizes of the two configurations, but chemically they should resemble one another very closely.

Mr. Coggeshall: Would this be true also for the doubly-charged negative ion of sulphur?

Dr. Foote: Yes, it also should resemble argon in many respects. X-ray spectra, however, would not be materially changed by the capture of the outer electrons, since these are determined primarily by the nuclear charge.

Mr. Jerome Alexander: Mr. Foote stated that all the atoms of any one element are alike. I should like to know if he really means that.

Dr. Foote: I should have said, more correctly, that all the atoms of a given atomic species are identical. The evidence for this is from the experimental standpoint, from spectroscopic data, from critical potential measurements, from direct observation on the amount of work required to pull out any particular electron from an atom. As far as our discussion to-day is concerned, the atoms of all elements are alike. The different isotopic species of the same element arise in differences in the formation of the nucleus or sun in the atomic planetary system. As long as this sun has the same charge, the planetary systems are practically identical. Hence all chemical, and the physical properties not directly related to the nuclear formation, are unaffected.

Mr. Alexander: I understand that the valency of the atom depends upon its outer electron ring.

Dr. Foote: Yes, since the forces acting in chemical reactions are not sufficiently great to produce changes deep in the interior of an atom.

Mr. Alexander: It has been frequently stated, and I believe it to be a fact, that there are six different kinds of mercury atoms and two different kinds of chlorine atoms.

Dr. Foote: Yes, some chlorine atoms weigh 35 and others 37. Aston's work indicates that there are mercury atoms weighing 197, 198, 199, 200, 202, and 204. *All* the chlorine atoms, however, have a nuclear charge of 17 units and *all* the mercury atoms have a nuclear charge of 80 units. These different species of the same element are chemically identical.

Mr. Alexander: We therefore have possibly 12 different kinds of calomel. (Laughter.) How about lithium?

Dr. Foote: I believe so, but chemically and physiologically they are all alike. Consider lithium, for example. Here we have two isotopes, one of atomic number 7 and the other 6. These are present

in any sample of lithium in the ratio 94:6 so that the mean atomic weight which the chemist measures is 6.94. The planetary system of each isotope is the same since the net charge on the nucleus, which determines this configuration, is 3 units in each case. The actual structures of the nuclei of the two atoms, however, are different. The one of weight 6 may be considered as made up of one helium nucleus, two hydrogen nuclei, and one electron. The nucleus of the isotope of weight 7 consists of one helium nucleus, three hydrogen nuclei, and two electrons. All of this structure occupies a very small volume compared to the actual volume swept out by the revolving electrons. These structures were represented as dots in the models illustrated, which even then exaggerate their size. Any physical and chemical property which depends upon the motion of the electrons will not be affected by slight changes in the nucleus so long as the nuclear charge is not altered. To a very small extent variations in the mass of the nucleus affect certain spectroscopic lines. Thus in lithium we should expect a very small difference in wave lengths of lines emitted by the two isotopes. Physicists at the present time are trying to discover such minute shifts, which have been definitely established so far only for lead. Physical properties or phenomena depending upon mass, such as density, centrifuging, fractional distillation, or deflections of the charged atom in electric and magnetic fields, will evidently show the presence of different isotopes, the latter method being employed by Aston in the direct determination of the atomic weights of isotopes. The presence of isotopes may be also detected by a study of band spectra of molecules. Here the entire atoms in the molecule revolve or vibrate in respect to one another, and the properties of the relative motions, and hence the spectra, will depend upon the masses of the rotating parts. Thus while the spectra of atomic chlorine of weights 35 and 37 are practically identical, small differences occur in the band spectra of HCl^{35} and HCl^{37}.

Dr. N. K. Chaney: When listening to Dr. Nels Bohr's lecture in New York I got the impression that in any mass of hydrogen atoms, for example, representatives would be found of all the possible planetary arrangements of orbits, and that while a quantum of energy was absorbed or emitted with a change from one orbit to the next higher or lower, each of those possible states was relatively stable when once established. Are we to understand that only one of the possible quanta orbits is stable? And that an electron in a second or

third quanta orbit immediately goes back to the first? Why does it go back and which is the stable configuration?

Dr. Foote: That is the unexplained thing. We make that as a postulate. It is the fundamental difference between the atomic system and the solar system. If you knock the earth out, it won't come back the same as it was before. But in an atomic system it comes back in the same position, the same orbit, the same condition, and we don't know why that is. The other orbits don't possess the same degree of stability. There is always one orbit which is the most stable and others with temporary stability, and the orbits in between have various standings.

This can not be explained. We make this postulate based on all experimental data. If the earth were ejected from its orbit, and should later return to the solar system, it would not revolve in the same orbit as before. But with the hydrogen atom experiments in spectroscopy and critical potentials show that there exists a discrete set of orbits which alone may be occupied. The electron finally settles down in the most stable of these states, where the energy of the system is a minimum. This happens to be a circular orbit with the radius $5.31 \cdot 10^{-9}$cm.

Mr. Alexander: What is the relation of the first, second, third, and fourth atomic positions?

Dr. Foote: For hydrogen they are in general ellipses with the major axes in the ratio 1:4:9:16, etc. For an alkali metal the dimensions of the possible orbits of the valence electron are not so simply expressed because the presence of the other electrons in the atom produces disturbances. The outer portions of these orbits, however, resemble Keplerian ellipses with major axes and eccentricities which can be read from the spectrum.

Dr. J. C. Olsen: Is there any agreement between the theories of Langmuir and Bohr?

Dr. Foote: To a considerable extent the Lewis-Langmuir theory as modified by Bury is a rough approximation to the Bohr theory of atomic structure. The electron on Bohr's theory is in the outer portion of its orbit for the greater part of the time. Its action to external forces, such as chemical reactions, could be therefore replaced roughly by an electron fixed at a point near the outer focus of the elliptical orbit. Bohr arrived at his scheme of atomic structure from a quantitative consideration of line spectra. The key to molecular

structures lies in the interpretation of band spectra, where progress is just beginning to be made.

A MEMBER: Does the valence electron revolve about the nucleus in solid sodium?

DR. FOOTE: In the gas or isolated atom the valence electron must revolve about the nucleus of its own atom. In the solid, however, the atoms are so closely packed that the valence electron is in the field of several atoms. Very likely the valence electron no longer knows to which atom it belongs. It may revolve about one atom for a while and then pass on to another. Possibly the looseness with which the valence electron is bound to an atom in the solid and closely packed state accounts for the presence of the "free" electrons necessary in the interpretation of metallic conduction.

PRESIDENT HOWARD: Is there any further discussion on this paper? If not we shall proceed to the next.

THERMAL RESEARCH AS A GUIDE TO ENGINEERING PRACTICE[1]

By H. C. DICKINSON

Read at the Washington Meeting, December 6, 1924

The chief function of research in its relation to engineering practice is the development of basic facts and principles which can be applied to the solution of engineering problems or can serve as a basis for further extension of engineering practice, in other words, to add to our engineering resources.

Thermal research in its relation to engineering may be classed for convenience under four heads:

(1) Temperature measurement and control.
(2) Thermal properties of matter and engineering materials.
(3) Thermodynamics and power production.
(4) Heat transfer.

The bearing of research along these lines on engineering practice, and particularly on chemical engineering, is illustrated by some specific problems which have been solved or given special attention by the Bureau of Standards.

Temperature Measurement.—Temperature determines to such a vital extent the properties of most materials that the subject of temperature measurement and control is sometimes neglected simply because of its universality. The extent to which the control of temperature enters into engineering processes, particularly chemical engineering processes, is so familiar as hardly to need illustration. Temperature is usually the most important of the physical conditions which determine the rate and nature of any chemical reaction.

The first essential in the specification and control of temperature is a temperature scale on which such specification can be based, meaning by temperature scale not Fahrenheit, Centigrade, etc., but the basic definition of a temperature scale. Shall it be defined by the expansion of mercury in some specified sort of glass or by the change of pressure of a fixed volume of a specified gas? Some of the most

[1] Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

painstaking work in the field of thermal research has been devoted to this subject, and much more remains to be done.

There has been for a good many years practical agreement on the temperature scale as defined by the change in pressure of a fixed volume of hydrogen under specified conditions. The scale internationally accepted for work of ultimate precision, however, is the absolute thermodynamic scale of Kelvin which may be derived from the scale of the hydrogen thermometer. Thus, for practical purposes all of our tables of thermal properties of materials are on a uniform basis in the ordinary temperature range, from, say, —40 deg. Centigrade, to 1064 deg. Centigrade, the melting point of gold. Where the highest accuracy is required, however, it is sometimes necessary, especially for observations dating back more than ten or fifteen years, to determine what the observers used as their definition of temperature. For temperatures below and above the range specified above there is some uncertainty in much even of the recent work. This last summer a series of conferences was held with the National Physical Laboratory of Great Britain and the Physikalisch-Technische Reichsanstalt of Germany to discuss international uniformity in defining the temperature to be used in the certification of temperature-measuring instruments. The three national laboratories have now reached a substantial agreement and it will now be sufficient to say that a given measurement in any one of the three countries was made in the International temperature scale in the range stated above. For temperatures below —40 deg. Centigrade and above 1200 deg. there is further research work to be done by the national laboratories before a uniform practice can be established.

Having an accepted scale of temperatures, the next essential is a means of making measurements. It is not practicable in most cases to use for engineering purposes the same sort of instruments which serve to define the temperature scale, as, for instance, the constant volume hydrogen thermometer or the laboratory type of platinum resistance thermometer, which latter is the working standard for all the standardizing laboratories, in the range —40 deg. to 650 deg. Centigrade. For most purposes mercury-in-glass thermometers are used at ordinary temperatures and thermoelectric thermometers at higher temperatures, up to the point where radiation or optical methods are required.

All of the usual convenient instruments, especially where accuracy is required, are subject to many obscure corrections. Mercury-in-

glass thermometers in particular may be in error by many degrees unless calibrated and used under carefully defined conditions. The error in the reading of a high-temperature thermometer with its stem exposed may exceed 30 deg. A vast amount of research has gone into the development of correct methods of testing and using temperature-measuring instruments. In fact, without the results of this work as incorporated in the design or certification of these instruments, or directions for their use, they would be almost valueless to the engineer whenever it is necessary to specify the actual temperature.

A special field of temperature measurement is that of pyrometry. Measurements of temperatures higher than those for which glass can be used have become common practice in many industries. The development of technique which makes it possible now to measure temperatures at the melting point of gold with a precision or reproducibility of a fraction of a degree is a result of research of the most painstaking kind. The application of reliable pyrometers to the control of many industrial processes, such as, for instance, the heat treatment of steel, has revolutionized the processes of manufacture of many articles.

The pyrometer of one sort or another has come to be the control instrument in many establishments which not many years ago were entirely dependent on the skill or, more often, the guesswork of one or two individuals to provide whatever temperature measurement was made. The country blacksmith may guess at the temperature for quenching a piece of carbon steel to make a passable rock drill but the same method will not apply at all to an alloy-steel gear to use in a high-grade automobile transmission. Quantity production of alloy steel parts would be an utter impossibility without accurate temperature measurement.

Another subject of diligent research is the control of temperature. Automatic devices for temperature control are applied to all manner of processes and installations from an incubator to an office building; from a cold storage house to a heat-treating furnace. Such devices appear at first sight to involve little research in a scientific sense but mainly inventive genius and development work. This appearance is, however, misleading. The principles upon which all successful thermostats must operate have been subjected to much scientific analysis. The Bureau has added considerably to this knowledge.

Thermal Properties of Materials.—In the Physical-Chemical Tables of Landolt and Börnstein, over 500 pages out of 1630 are devoted to the thermal properties of materials. This material represents a record in very condensed form of some of the most immediately useful information contributed by thermal research to the engineering and scientific resources of the world. Some of the contributions of the Bureau of Standards to this class of information are:

(*a*) A complete set of measurements of the properties of anhydrous ammonia, essential to the design and economical operation of refrigerating machines. These data have been incorporated in a set of tables which are probably more accurate than those for any other material.

(*b*) A similar study of the properties of water and steam is being made, partly in conjunction with other institutions. The properties of water and steam at the high pressure and temperatures now common in central power plants are at present not known with sufficient accuracy for engineering practice, hence the need for further research.

(*c*) Another important engineering constant is the latent heat of ice. Accurate measurements of this and of the specific heat were made by the Bureau some ten years ago.

(*d*) Heats of combustion of coal, oil, gas, and other fuels are essential engineering data. The Bureau has assisted in developing accurate methods of measurement of these heats of combustion and now furnishes the engineering laboratories of the country with certified standard combustion samples by the use of which the measurement of heats of combustion throughout the country is maintained on a uniform basis.

(*e*) The melting and boiling temperatures of some standard substances are required to afford reference points on the standard scale of temperature. A number of these points have been measured by the Bureau for this purpose. Among these are the freezing point of mercury, the boiling points of naphthalene, benzo-phenone and sulphur, the melting points of tin, antimony, aluminum, silver, gold, copper and, recently, a very accurate determination of the melting point of palladium; that of platinum is to be determined in the near future. Measurements of these temperatures have been made, of course, in other laboratories as well, so that the generally accepted values

rest upon a weighted mean of a number of independent observations.

Under the heading of Thermal Properties of Materials may be classed another important contribution of the Bureau, namely, the securing of information on the fire-resistive properties of structural materials and of buildings. Some years ago an extensive investigation was made into the behavior of more than two hundred typical building columns under the combined action of fire and load, thus supplying a mass of accurate engineering data in a field where there was practically no reliable information. This line of research at present covers the fire-resistive qualities of building walls of many classes; the fire-resistive qualities of fire protecting curtains for theatres; of safes for protecting documents; and of roofing materials. It includes a critical study of the conditions of temperature which are to be expected in fires occurring in various types of building occupancies, such as offices, factories, storehouses, etc., to serve as an index of the destructive effects to which different classes of buildings are subject.

Thermodynamics and Power Production.—While the production of power from fuel, and allied engineering processes involving the application of basic principles of thermodynamics were initially to a large extent purely engineering developments, the trend of engineering practice has been toward a greater use of accurate basic facts, and there has been a constant demand for more accurate knowledge of the thermodynamics of the processes involved. This is particularly true, for instance, of the internal combustion engine in its application to aircraft, where the highest efficiency is required with a maximum output of power, per unit weight.

In this particular field the Bureau has added materially to our stores of information by years of intensive work on the performance of such engines under all conditions of atmospheric density and temperature met with in practice at all altitudes. This work includes investigations of the effects of density, temperature, types of fuel used, air to fuel ratios, etc., on the efficiencies and power output of the engines. The work of the Bureau is unique in this particular line. In connection with this work on aircraft and other internal combustion engines the Bureau has added much to the knowledge of the phenomena of combustion of fuels under the conditions occurring in engine cylinders. This phase of the power production problem

has come to be recognized as of the utmost importance if the maximum service is to be had from our petroleum resources.

The researches on power production have inevitably led to other allied lines of research which, although not strictly thermal, are of equal importance. For instance, an investigation by the Bureau of the behavior, thermal and mechanical, of friction materials used for lining automobile brakes has led to such changes in the production of this material that the average life of brake linings has been doubled, and of even greater importance, perhaps, is the fact that a study of these materials and their possibilities is likely to lead to important changes in engineering practice which will greatly increase the safety of vehicular traffic.

Heat Transfer.—Scarcely one individual factor in engineering practice and particularly in chemical engineering is of more general importance and application than that of heat transfer in some of its many forms.

Every process which depends in any degree upon the use or disposal of heat or on the control of temperature involves from one to many phases of heat transference. From its very universality perhaps this phase of thermal research has received far less attention than its deserves. From the point of view of engineering practice, however, there is probably no other field of equal importance which is so little understood or in which there are so few reliable data readily available to the engineer. Just why this should be so is not easy to fathom. Heat transfer perhaps is not the most difficult field of thermal research. In fact, much excellent work has been accomplished in this field and scientific data are available which cover the major part of it with reasonable completeness. The application of these data to practical problems of engineering is, however, rather difficult and requires a type of study which is not generally familiar to the engineer.

The familiar divisions of this subject are as follows: modes of heat transfer are by conduction, convection, radiation, to which may be added evaporation and condensation. The latter applies to steam boilers and evaporators and condensers of all kinds where the evaporation or condensation takes place at heated or cooled surfaces. Under these conditions the actual process of heat transfer differs radically from the usual conditions where the heat of vaporization is not involved. In condensers, in particular, the presence of minute per-

centages of non-condensible gases as air in steam or nitrogen in ammonia has a disturbing effect out of all proportion to their amounts.

Heat transfer may take place through solids, liquids, or gases, or between any of the three states of matter. Also the conditions under which transfer takes place, particularly where conduction in solids is concerned, may be those of the steady state where the temperature distribution is constant as for processes requiring a long period of time, or they may be those of changing temperature. In the latter case not only the heat conductivity of materials is important, but also the heat capacity. These two conditions are mentioned particularly because failure to distinguish between them is one of the most frequent causes of error and confusion in heat transfer problems. For instance, in intermittent processes involving heat, the heat capacity of the materials such as furnace walls may be a predominating factor, the more so the more frequent the periods of heating become. If a gas oven were to be fired up for intervals of only a few minutes at a time, it might be more economical of gas to make such an oven of thin sheet metal only to reduce the amount of heat necessary to heat the walls themselves, whereas if the same oven were to be used for longer periods the economy would depend mainly on the heat conductivity and not the heat capacity of the walls.

Most of the mathematical equipment and many of the physical data necessary for the guidance of engineering practice in the lines suggested here is available as mentioned above, but there is still much need of further research in putting existing information into usable shape, and in filling in gaps.

A recent project completed at the Bureau illustrates this. The problem presented was the recovery of sufficient water from the exhaust gases of an airship engine to equal the weight of fuel burned, the water to be used as ballast to maintain a constant weight without loss of lifting gas. The use of helium gas in airships would be utterly impracticable without some such device. The problem proved to be one of direct cooling and surface condensing, of the exhaust products in tubing cooled on the outside by direct air flow. The limitation of weight to less than two pounds per horsepower of engine necessitated the most economical use of material and of cooling surface.

The solution of this problem involved a wide range of data on the coefficients of heat transfer between gases and metal surfaces for

various gas velocities, both with and without the presence of condensible water, and some rather difficult mathematics. While some of these data were to be found mainly among the results of earlier researches of the Bureau, many new data were needed for the final solution of the problem, and although this was accomplished for the particular conditions specified much more research is needed to make the solution general.

Previous researches of the Bureau in this particular field of air cooling comprised a very extensive investigation of cooling radiators for aircraft. The practical engineering information of air cooling or heating is mostly confined to velocities of 20 feet per second or less and is not at all applicable to velocities of 100 to 300 feet per second and over as involved in the aircraft cooling problem. The results of this research, while directly applicable to aeronautical engineering, have shown the possibilities of transferring heat at very high rates per unit area of cooling surface and with high efficiency. Such information makes available new possibilities in engineering practice along this line.

Other heat transfer researches in which the Bureau is actively concerned are heat transfer through insulating materials for high and low temperatures and through structural walls. The conductivity of materials is determined by measuring the heat flow through a fixed area of a flat slab, under a given temperature gradient. By a simple reversal of the process, that is, by measuring the temperature gradient in a flat slab which has been previously calibrated, it is possible to make a meter which, applied to a wall, serves to measure the flow of heat per unit area through the wall. This method, which was tried out at the Bureau some six years ago, and is now being used in a series of measurements of heat transfer through building walls, has received favorable consideration elsewhere, and promises to become one of the most useful methods for measurements of this kind. Still another heat transfer problem concerning which there is little reliable information is transfer across air spaces within which there is free circulation of air. A limited research on this problem was reported some time ago and this is being continued. The results are needed in the design of, or in calculating the heat transmission for, all sorts of constructions in which air spaces are included, as, for instance, multiple windows, hollow tile walls, many refrigerator walls, and various types of ovens, etc.

In general it appears that thermal research covering the various phases of heat transfer can serve engineering practice in more different ways than almost any other field of research.

The following are some applications of such data: improvement of the capacity and efficiency of condensers and heat exchangers in processes depending upon intermittent heating; economies in the design of insulating furnace walls; more reliable information on heat penetration in processes which require the heat treatment of solids, especially of poor conductors, as in the vulcanization of rubber; the adjustment of temperature distribution in kilns, ovens, etc., by adjustment of the heat losses at different sections. In fact, there is scarcely any engineering process which would not profit by research on the subject of heat transfer.

Discussion

[At the completion of the presentation of this paper and before opportunity for discussion, the President of the United States, at 12.35 p.m., began reading his first message to Congress at the Capitol, to which the members of the Institute listened as reproduced by the radio. Upon its conclusion, at 1.40 p.m., the convention recessed.]

RAW-MATERIAL TRADE SURVEYS OF THE DEPARTMENT OF COMMERCE

Read at the Washington Meeting, December 6, 1923

By JULIUS KLEIN [1]

The subject of essential raw-materials is a very broad one and constitutes a problem that is even more insistently coming to the front. With the outbreak of the World War we realized our absolute dependence and critical need for many raw materials that are available only in foreign lands. Since the conclusion of the war the serious effects upon the everyday life of our people that arise from foreign control of raw materials have become more and more a matter of grave concern. This result has been evidenced through shortage of supplies or through enhanced prices and has been felt by our manufacturers, farmers, and every class of industry and trade down to the ultimate consumer. The importance of this situation was realized by the Department of Commerce and a fund was appropriated to it by Congress for a raw-material survey during the fiscal year 1923–24. The fund so provided for this Department amounted to $400,000 for an investigation of conditions of production, marketing, and the possibility of our development of sources of crude rubber, nitrates, sisal, tanning extracts, and other essential raw materials for American industries now produced under foreign monopoly control. In substance, it devolved upon the Bureau of Foreign and Domestic Commerce to devise in any measure that might be practicable, some solution for this situation.

Investigations were immediately undertaken on the specified items, and important progress has already been effected.

The Crude Rubber Survey

Among the most essential raw materials that are products of the soil, the sources of our crude rubber imports occupy the unique position of being mainly concentrated in one geographical region. Lying in the extreme southeastern portion of Asia and adjacent islands, this region is about as far removed from us as it could possibly be. It is,

[1] Director, Bureau of Foreign and Domestic Commerce.

moreover, mainly under control of the British and Dutch, and the bulk of the planted area, amounting to something over 3,000,000 acres, is controlled by British capital. American capital in this region has at the present time only 100,000 acres, or 3 per cent of the total.

Even before British restriction went into effect, the danger of having so important a product as rubber concentrated in one remote geographic region was clearly recognized. The sources of danger are war, plant pests, and diseases, and internal labor disturbances. War between two first-class powers, especially if one of these has possessions in the Far East, would operate to cut off or greatly restrict our importations of crude rubber. Should an uncontrollable disease get started, it might be so serious as to wipe out the entire production and the world would be almost without rubber. This is what happened to the coffee of that region at one time, and, in fact, the rubber plantations rose in the beginning principally on the ruins of coffee plantations. The third menace is the possibility of internal disturbance in India and Java, or both, where most of the labor for the plantations is obtained.

These dangers, however, were too remote to compel action, and it was only when the so-called Stevenson Restriction Act was enacted by the British Colonial Government that Congress appropriated funds to investigate the possibilities of other regions for growing rubber. I do not propose to discuss this restriction in detail except to say that by it the exports of rubber from British controlled areas were reduced to 60 per cent of the normal output in order to raise the price of rubber. The claim was made that without such restriction many of the planters would become bankrupt. At present, the price of rubber is nearly double what it was before the restriction went into effect. It is doubtful, however, whether all this increase in price is due to the restriction scheme. Improved conditions of the American market demand probably account for a part of it.

During the first six months of 1923, the United States imported nearly 60,000 tons more rubber than during the same period of 1922, an increase of 39 per cent. During this time, the net exports from British Malaya and Ceylon decreased some 2,000 tons as compared with those of 1922. The increased imports into the United States were made up from two sources, viz., accumulated stocks in London and elsewhere and increased exports from the Dutch East Indies and

other regions, including wild rubber from various countries in Latin American and Africa. Thus other producing regions are profiting by the restriction.

In the past, efforts to start plantation rubber in other regions than the Far East have not been successful—mainly because of unfavorable economic and political conditions. Other factors that have operated have been the choice of the wrong species, mismanagement, and ignorance of the planters concerning the best plantation methods. Up to date, no impartial survey has been made of the possibilities in many of the regions where climatic and soil conditions seem favorable, nor have attempts been made recently to introduce plantation rubber in them. Since previous efforts were made, economic and political conditions may have improved. In fact, there are indications that they have.

The parties of the Department of Commerce now in the field are expected to cover approximately fifteen different political units where the physical conditions seem favorable for the production of Para rubber. The regions being examined are the Amazon, certain countries bordering on the Caribbean Sea, and the Philippines. One party is gathering statistical information, including cost data, in Malaya. It is hoped that progress reports made by these different parties will furnish some material to be released from time to time. The final report, however, will have to await the completion of the field investigations, and its final review by the Washington authorities.

Owing to lack of time and funds, all tropical regions where the physical conditions for growing rubber seem favorable are not being investigated. It is expected that funds will be appropriated for extending the field investigations and for making more intensive studies of those countries where the economic conditions seem most favorable for success.

The Chilean Nitrate Survey

Chilean nitrate falls within the scope of the Raw-Materials Survey since it is a material basic to many of our industries and of utmost importance in national defense, aside from its wide use in nitrogenous fertilizers. The price of Chilean nitrate is fixed from year to year by the directorate of the Chilean Nitrate Producers Association in Chile, and for economic reasons this price controls the prices

of other nitrogenous materials which complete with Chilean nitrate in the world's markets.

The matter of the Chilean nitrate supply and the price thereof, however, is only a phase of the much larger general problem of the world's supply of and demand for nitrogen compounds, and it is profitable to consider the Chilean nitrate question only in reference to this larger problem. The World War brought home to all of the belligerents the necessity of an assured and abundant supply of nitrogen compounds and the danger of relying on a foreign source of supply. As a consequence of this war lesson, there has been great activity in the field of nitrogen fixation since the war, both in Europe and our own country.

In referring to the relation between nitrogen and explosives, we are too apt to forget that the manufacture of explosives, which is an activity enormously stimulated by war, is by no means solely a war-time industry. Dynamite and similar blasting materials are now finding wide use in road-building, quarrying, mining, and the large construction work where their use involves a great saving of labor. The manufacturing of explosives, therefore, is to be regarded as a peace-time industry, whose development gives us a valuable asset in time of war. There are, of course, many other peace-time industries that involve the use of nitrogen compounds, as, for example, the manufacture of dyes, artificial silk, leather substitutes, glass, fireworks, celluloid, and a host of other articles that need not be named to men in the chemical engineering profession.

Nevertheless, our chief interest in fixed nitrogen does not lie in the fact that certain nitrogenous organic compounds are explosives, nor in the fact that nitrogen in its various forms is one of the key substances of industry as a whole, but does lie in the fact that a plentiful supply of available nitrogen in the soil is one of the conditions for large agricultural crop production. This phase of the nitrogen problem is not only a matter of national concern but is of peculiar interest because of the unusual situation that is now evolving in American agriculture. The industrial development of the United States has been phenomenal, and the standard of living established here is the highest yet attained. These achievements have been possible largely because of the vast potential acreage of fertile farm lands into which agriculture could expand. This has permitted American agriculture to develop an extraordinary type of farming,

quite different from that which exists in the older agricultural nations of the world.

We have already reached the point where the amount of land that can be brought under cultivation is small compared with what is already cultivated. There is, at the same time, no decline in our growth of population, and this means that our food consumption will eventually overtake food production and there will be upon us the urge to produce more food per acre. This state of affairs has been reached by the older nations of the earth, and they reached it so far back in their national development that they had but one course to follow, namely, to put more labor on the land in order to secure the increased food production; in other words, apply intensive methods of agriculture. To-day, however, we have a choice in the matter of meeting increased food production per acre, for instead of increasing the number of agricultural workers per acre we can apply the labor-saving method of using highly developed implements, and especially increased amounts of commercial fertilizers. The most expensive element of these commercial fertilizers to-day is the fixed nitrogen that they contain.

The nitrogen problem is then, as we see it, to secure adequate supplies of nitrogen compounds at a price that will permit their free use in all important application. The consideration of national preparedness imposes the condition that there should be available domestic supplies of fixed nitrogen sufficient to meet a war-time demand for military explosives, but beyond this the problem is chiefly a question of price, since it appears that, at the present prices prevailing for nitrogen compounds, it is not possible, economically speaking, to apply to the soil nitrogen compounds sufficient to maintain existing soil fertility, to say nothing of securing the increased yield to meet the new situation that is developing.

It has been the aim of the Nitrogen Survey to review and bring up to date our information regarding the developments of the air nitrogen industry, and for this purpose we have not only consulted those who are engaged in the industry in this country, but have sent representatives abroad to study the situation in Europe. We have made a special study of the Chilean nitrate industry, through representatives in Chile, primarily to determine what further economies might be effected in the production of Chilean nitrate. Anticipating that the development of the air nitrogen industry will eventually force

conditions of competition in Chile such that only those who make economies in production can survive, we are particularly interested in knowing how far Chilean nitrate prices can be reduced to meet the competition which we expect will develop with the growth of our domestic air nitrogen industry.

Our sources of domestic supply of fixed nitrogen have been studied, particularly the coal processing industries, in order to arrive at some idea of what increases in production may be expected with the normal growth of these industries.

It is recognized that there is a voluminous literature dealing with various phases of the nitrogen question, and it has not been easy, in preparing a report on the nitrogen problem, to select from the available data such as would serve our purpose. We have endeavored, however, to present a view of the nitrogen problem as it exists to-day and to evaluate the various factors in the situation, particularly to take cognizance of new elements that have entered the situation as a result of the war and the developments that have followed in the years since the war.

The Sisal Industry

Sisal, in view of its resistance of weather and the ravages of insects which destroy most of the other twine materials, is in very great demand by the American grain agriculturist. The principal source of production of this fiber is Yucatan, Mexico. Practically the entire production of this commodity is exported to the United States. In view of this fact, together with indications of monopolistic tendencies, the subject is under investigation by special men in the field.

Miscellaneous

There are many commodities that come within the scope of the spirit of the appropriation, on which no exhaustive investigations are being carried on, but in connection with which surveys are being conducted by the various commodity divisions within the bureau. As illustrative of this:

In March, 1923, the Tanners' Council of America requested that a survey of the domestic resources for new tanning materials, including production and consumption of domestic tanning extracts, be made. An advisory committee was appointed, consisting of three leading members of the importers of tanning materials, to cooperate with the Hide and Leather Division on this investigation.

The purpose of the investigation is to report to the industries interested the exact position as regards the domestic supplies of tanning materials and to recommend steps that should be taken to insure an adequate supply of domestic materials in the event of eliminating the use of foreign tanning materials.

By the end of the fiscal year complete figures were obtained on production of domestic tanning extracts. These figures have been analyzed to show the total amount of liquid and powdered extracts produced during the year 1922. The consumption of domestic woods and barks was also determined, together with the stocks of wood and bark on hand January 1, 1923, as well as the yield per pound of liquid chestnut extract, including production of powdered extract by States, and the yield per ton in pounds of liquid and dry hemlock extract, liquid and dry chestnut oak extract, and liquid and dry sumac extract by States. The detailed consumption of extracts and barks was ascertained from more than 90 per cent of the tanners of the country, and these figures were compiled and reduced to bark tons so as to be comparable with the production figures.

Through the hearty cooperation of the Forest Service new estimates were obtained as to the stands of chestnut timber. The Bureau of Plant Industry, Department of Agriculture, furnished a complete report on the chestnut blight and is at the present time studying suggested methods for retarding the blight and reforesting the blighted areas. Through the active aid of the Bureau of the Census and the Lumber Division, figures and estimates were furnished for the production and consumption of chestnut timber.

The advisory committee decided, in view of the quantity of chestnut timber immediately available, that it was not necessary to pursue an investigation of foreign tanning materials or to study the possibility of cultivating tanning materials in the tropical possessions of the United States. The advisory committee further decided that in order to make this report of the greatest value to the leather industry it was essential that a 100 per cent return be had on the questionnaires regarding consumption of tanning materials, and work along this line is being continued.

The Mineral Section of our Iron and Steel Division is interested in the current and future outlook of an extensive group of metals and metallic salts.

Tin, one of the base metals which, as a raw material, is so very essential to the great American canning industry, is conspicuously

absent from the list of natural mineral resources found within the continental confines of the United States. We can safely assume that our Geological Survey has made a thorough investigation into the domestic mineral deposits of this country. Due to the fact that we are a non-producer of this essential metal (element), and because we consume about 54 per cent of the World's production, we are compelled to purchase our supplies from foreign sources. Here it behooves the American Chemical Engineer to turn his energies towards the discovery of a substitute which will if necessary, perform the same functions as this essential metal. Through extensive research it has been found that, in many cases, alloys of lead, antimony, and other metals (elements) may act as a substitute in certain bearing metals and solders. But the victory will not be won until some substitute, in the form of a varnish or covering of some description, is found which may, without, harmful consequences, be brought in contact with preserved foodstuffs. Only after such a discovery has been made will we be in a position to consider ourselves independent of the metal, tin.

Lead, one of the first known metals, used extensively by the Phonecians, will soon be considered a luxury unless new deposits are located. With the advent of the electrical industry which is a very large consumer of lead, there have been very few, if any, new deposits of this metal discovered to offset this drain on our natural resource. Therefore, in the distant future, the Chemical Engineer may be called upon to furnish a substitute for this element.

Platinum, the head of the rare metals, is inadequately produced within our borders. It is reported that the Russian deposits, formerly our greatest source of supply, are becoming depleted, and the newly discovered deposits in Colombia are as yet undeveloped. The possibilities of utilizing this element appear to be limited in accordance with the available supply. Therefore, is there not a field open for research which will provide alloys that may take the place of this metal in industry?

While on this subject I might mention chromium which is so vital to the steel and tanning industry. Here again, like tin and platinum, nature has forsaken us. We are obliged to import practically all of our supply of this necessary element from abroad. There are other substances such as manganese, tungsten, nickel, molybdenum, vanadium, antimony, bauxite, mica, cryolite, and certain clays which,

although produced to some extent in this country, are of an inferior quality and do not meet domestic requirements. Foreign existing sources or deposits of these materials avail us but little. The every day use of these commodities in the home and in the industrial processes catering to the essentials of daily life bring out the demand for cooperative research.

Surveys are being constantly carried on and information of a highly pertinent nature is being compiled and kept up to date on many of these materials in cooperation with the Geological Survey.

The Chemical Division of the Bureau is interested in commodities basic to all industries, and is, therefore, vitally concerned with practically all essential raw materials. It is confronted with a host of problems submitted by various sections of the chemical trade. China wood or tung oil is an outstanding example. This commodity, as the name implies, is exclusively of Chinese production. It is used for manufacturing the highest-grade varnishes. There is no other known supply available as a substitute. We import approximately one million dollars' worth per month, and the amount is increasing at a phenomenal rate. Records show that approximately two million dollars' worth were imported for June and more than that amount for August. In view of this fact, the paint and varnish industry has manifested a keen interest in the future outlook.

As a result, the Chemical Division has issued a Trade Information Bulletin which is a complete story compiled from original sources, covering all marketing phases and the future aspects as controlled by the efforts of American interests to undertake the successful production of oil in this country. Gums, resins, and lacs used in adhesives, varnishes, inks, textiles, medicine, cosmetics, etc., are imported to the value of approximately three million dollars per month. These are practically all of foreign, tropical or semitropical, origin. Essential oils, botanicals, roots, herbs, and berries may be listed in the same or a comparable category. It is difficult to appreciate the degree to which these commodities enter into the industrial processes of to-day and, consequently, how important it is to have a thorough knowledge of current source data, future outlook, supervision over monopolistic tendencies, and the possibility of domestic production or the evolving of substitutes.

As representative of commodities within this essential group, mention may be made of camphor, menthol, agar-agar, quinine, and

iodine. With the exception of iodine, these materials are of Far Eastern origin. Quinine, it is true, is native to a few South American countries also, but the bulk of production is centered in Java and closely controlled by Dutch interests. This syndicate fixes the price, controls the production, and allocates the distribution throughout the world. Practically the world's supply of iodine is centered in Chile. Here too a syndicate exercises control. The price has served to confine this element to the medicinal field. An element as active in synthetic processes as iodine should find practically unlimited possibilities in the field of dyes, metallurgy, tanning, etc. (As progress is made along the line of development, it is reasonable to suppose that the syndicate will see the advantage of placing all of the available crude stock on the market rather than in conformity with the current policy of releasing but one-fifth of this amount.) Camphor, menthol, and agar-agar are Japanese-controlled, and the effect is very strongly felt in this country which is the largest consumer of these products. Progress in the production of pyroxylin plastics, pharmaceutical and toilet preparations, and many other classes of products is seriously retarded or indirectly controlled by this monopoly of raw products. The agriculturalist is vitally concerned with potash. Here we have at present two syndicates arrayed against one another in an endeavor to capture the world market. A combining of interests, however, would work decidedly to our disadvantage.

There is no doubt in the mind of any of us that all of these materials should be thoroughly investigated on the ground and action taken in accordance with the suggestions embodied as a part of such a survey.

Our wide expanse of country, with its many advantages from the standpoint of climate, fertility, etc., is undoubtedly adapted to cultivating the natural products. It is even within the range of possibility to foster material interests by engaging in a reciprocal production program with our sister countries on this continent. This policy, I feel certain, would result in increased trade with these countries in all commodities and would engender a cooperative spirit based on mutual helpfulness.

Many of these products, however, are within the development sphere of the chemist. Some have already been produced, for others there are substitutes, but our efforts along this line are stifled by cutthroat competition from natural or established sources, showing the

need of protective legislation and a sympathetic, forebearing, and willing attitude on the part of the consuming industries as well as the ultimate consumer.

It is the desire of the Department of Commerce, through the Bureau of Foreign and Domestic Commerce, to receive such assistance as will permit us to carry on these essential surveys with a view to educating the country in the need for thought and action on this subject. We cannot expect to rectify a condition until the absolute necessity of certain commodities and our dependence upon them are forcibly brought home to everyone. It is folly to pay the exorbitant toll exacted, curtail our production in accordance with the material allotted, or permit our development to be retarded by foreign monopolies, internal disturbances, or other adverse conditions.

Discussion

President Howard: Are there any questions?

Dr. Maximilian Toch: Dr. Klein has sounded a very important note when the mentions that his department is attempting to exploit the planting or the production of China oil wood. It may be interesting to know that shortly after the war the United States Navy determined that a number of materials must be produced in this country in order not to place this country in the same predicament that it was placed in during the war. For instance, the use of material such as Chinese wood oil and shellac. The Navy is now attempting to make ship-bottom paint and other paints out of American materials. Dr. David Fairchild as far back as 1912 succeeded in planting the tung oil tree as far south as Miami. The tung oil tree has been planted in Texas, experimentally, but nothing was accomplished until lately, when there was a large tract planted in Florida.

I am very glad that Dr. Klein's department is taking an active interest in this cause, and there is no reason why we should not grow that important plant in the United States. Until as late as 1906 people stigmatized China wood oil as not good because it was lower in price. Since that time we feel that we could not run our factories without that material. And there is no reason why in this immense country, with climates of all kinds and conditions of all kinds, we should not have the assistance of the Department in the production of this important material.

[Discussion closed.]

RESEARCH PROGRAM OF THE DEPARTMENT OF AGRICULTURE

By E. D. BALL [1]

Read at the Washington Meeting, December 7, 1923

The present organization of the Department of Agriculture as a whole, is not the result of any predetermined plan or policy but originated as the result of a number of happy accidents. Starting in a patent office and dealing with plants and animals in the simplest way it gradually gathered momentum, acquired an animal husbandry phase through the accident of the introduction of pleural-pneumonia and the organization of a unit for its eradication, a scientific phase through the office of microscopy, gradually enlarged and expanded its field, took on the weather service and the forest service, and with gradual enlargements and reorganizations has reached its present status of power and efficiency.

A study of the history of scientific organizations would show that research rarely grows symmetrically. It would be theoretically possible to establish a well balanced program of research looking to the development of the highest type of agricultural industry, but even if a new organization of perfect symmetry were established it would not long remain such. One leader with a larger vision and better organizing ability would forge ahead, open up new fields and tremendously broaden the scope of his work. Another would gradually work into a narrow line of endeavor and his organization would remain practically stationary. Even if it were theoretically possible to maintain a perfectly balanced organization it would likely find itself entirely out of harmony with agricultural development which in itself is not symmetrical. As for example, note the tremendous increase in emphasis upon marketing, farm management, cost of production, and other phases, in the last few years.

When former Secretary Meredith asked the writer to take a leave of absence from Ames and accept the Assistant Secretaryship it would have been promptly refused had it not been coupled with the further request that the year be devoted to a study of the possibility

[1] Director of Scientific Work.

of strengthening the research work of the Department. Here was a constructive problem that offered possibilities far beyond the capacity of the individual selected. It was accepted, however, with the idea that the year would afford opportunity to make some constructive suggestions for further lines of development. Only a few months were needed to determine that three radical changes must be made in departmental policy before there could be any hope of developing an efficient program of agricultural research. These three changes were as follows:

First. An organization looking towards the coordination of the work of the different Bureaus and the establishment of cooperative relations with state and other research agencies whereby all the work upon a given problem might be organized towards its successful prosecution, thus eliminating overlapping and duplication with their consequent jealousies on the one hand, and the neglect of important factors necessary to the solution of the problem on the other. The division of the work of the Department into its three functions of research, regulation, and extension, and the creation of the Offices of Directors, were offered as the first step in the solution of this problem.

The day was when the Secretary of Agriculture could himself attend personally to the work of the various Bureaus but that day has long since passed. The manifold duties of the Secretary as an advisor to the President and as a representative of the administration entirely precluded the possibility of the detailed administration of between 30 and 40 million dollars worth of scientific work. It would be like suggesting that a President or Chancellor administer a great state university without the assitance of the Deans, or the Directors of Experiment Stations and Extension Work, only that the Department of Agriculture is a much larger establishment than any university.

The second fundamental need, and even more vital than the first mentioned, was the possibility of paying adequate salaries to the scientific workers. The maximum salary that could be paid to any scientific worker in the Department had been fixed by law at $4,500. At the time this sum was named by Congress it was a reasonable compensation but the ever rising cost of living throughout the nations during the war period, especially in the Capital City, rendered the scale of compensation in the Department pitifully inadequate and

forced wholesale withdrawals. This process began early in the war period and reached its climax with a 54 per cent turnover in the Department in 1919. No scientific, or other organization for that matter, can possibly hope to maintain efficiency under such conditions.

The third necessity of the situation was a provision for prompt publication of the research work. Nothing is more discouraging to a scientist after spending a long period in painstaking research than to find that after the preparation of the results there is no money for publication and such had been the case for a number of years.

Instead, therefore, of attempting to strengthen the program of research of the Department the writer bent his entire energies towards the solution of these three problems, believing that he was contributing more to the possibility of research than in any other way. In the course of two years the three directorship positions had been created, the maximum salary had been raised from $4,500 to $6,500, an adequate publication fund had been provided and it now appears possible to turn attention to developing the research work itself.

A fourth inimical factor was discovered and steps taken to remedy it. The different Bureaus of the Government take a very large number of young scientists each year into the lower positions of the service. Strange as it may seem in the Capital City of a great nation, practically no provision was available for the graduate training of these young scientists so that they might advance to the higher positions.

The establishment of an unofficial system of graduate training for the workers of the Department was undertaken and has proved to be exceedingly helpful. Encouragement has also been given to workers to take up graduate work in the standard institutions and the graduate work in the Department has been so shaped as to encourage students to go to these institutions and complete their courses. This has had a very wholesome effect on the morale of the workers and has been especially beneficial in making positions in the Department attractive to the better class of younger research men in this institution.

At present the Department of Agriculture is expending between eight and nine million dollars annually on agricultural research. The experiment stations of the country are expending about five million and the industries are expending on research that is or should be

contributing to agriculture a sum that probably exceeds that of the stations. This makes approximately eighteen million dollars used annually in agricultural research in the nation, a sum almost exactly equal to the money expended in the extension of agricultural information to the people. The extension work has developed into one great organization and is essentially cooperative. There is no question that a similar cooperative relationship with reference to the three research agencies would materially increase the contribution made. It is therefore the ambition of the Department of Agriculture so to organize its program of research as to provide outstanding leaders in the respective lines, these leaders to be especially selected with reference to their ability to inspire cooperative relations. Other things being equal, the more outstanding the national leader the more easily will cooperative relations be established, provided he has the right attitude toward cooperative work and a fair amount of organizing ability. In this program the Department does not desire to dictate the problem or direct the approach but what it does desire is to bring into conference all of the men seriously engaged in the solution of a problem, establish the principle of round table, and work out a program to be followed in the attack and to subdivide the work and the responsibility so that each individual may contribute the maximum to the entire project and maintain leadership in his indivdual field.

Scientific workers connected with industrial firms have certain restrictions with reference to utilization of their results. I am happy to say that the situation with respect to this has been rapidly improving in recent years and many of these scientific workers are nearly as free to use their results as are the workers of the Government and State. As this attitude of mind increases with corporations it will be possible for the state and national workers to cooperate much more freely and to contribute materially to the development of the industries and at the same time utilize the research of the industries insofar as it applies to the development of the national problem. The attitude of the Department of Agriculture in the past has been to discourage the scientific worker from entering the commercial field. While the Department does not at this time wish to lose the services of its better grade of scientists, it realizes that many times a scientific investigation may lead to the possibility of a great commercial or industrial development and the scientist who has carried the process to the point where this undertaking will be possible is the best fitted to

carry it to a successful conclusion. Its policy will therefore be to give leave of absence to such scientists for the period necessary for the establishment of the industry, believing that this experience will in many cases be valuable in broadening his point of view and at the same time may afford him opportunity to add to his saving and sense of financial security, all of which is conducive to better scientific work and greater achievement.

The contributions of scientific research to agricultural development in the past have been enormous. In fact the entire structure of modern agriculture is founded on scientific discoveries. It will, however, only require a hasty and superficial survey of the situation to indicate that the opportunities for still further contribution are even greater at this time than they have ever been in the past. Certain fields of agricultural research have been almost entirely neglected up to the present time. Probably the most outstanding one is the weed problem. Weeds undoubtedly do as much or more to reduce the annual crop production as do insect pests or plant diseases, and yet they are just beginning to receive attention. The utilization of agricultural products is another field that is full of possibilities. The small sums that have been expended in this direction have given results that indicate the value of a very much greater expansion. In the early days of the agricultural experiment stations the chemist was much in evidence and much of our best scientific work was from that source. The application of chemistry to the industries in the last decade or two so overshadowed its use in agriculture that the chemist largely turned his attention to other fields. The time has come when other lines of agricultural research have forged much farther ahead than the chemical one and we now need a much greater application of chemistry to the complex problem of soil and plant relation, plant adaptation, disease resistance, drought resistance, and even to the chemistry of pathological conditions. In the same way we need to know more about the chemistry of fertilizers and the chemistry of colloids as applied to agricultural problems. The chemistry of insecticides is one of the most promising fields at the present time, both from the standpoint of the development of new insecticides and the investigation of the fundamental principles which determine the value of a given one. We need to know much more about nitrogen fixation in nature. We want to know about nitrogen fixation in the wheat plant as well as in the chemical plant.

One of the outstanding possibilities of the strengthening of the research features of the Department and the development of closer cooperation with other agencies is the possibility of organizing great national campaigns for the elimination of pests and diseases that require a unity of action over a wide area for their accomplishment. The Department has eradicated pleural-pneumonia, several outbreaks of the foot-and-mouth disease, a number of isolated infestations of the Gipsy and Brown-tail moths, has eradicated the citrus canker from the commercial orchards and expects entirely to eliminate it from the Gulf region. It has had notable success in reducing the area of the pink bollworm, the complete eradication of the Texas fever of cattle seems to be in sight, the barberry eradication campaign is progressing rapidly in the Upper Mississippi Valley, and tuberculosis eradication is now in full swing in every state in the Union. With the closing up of some of these lines of effort the Department should be in position to undertake to eliminate other great national menaces. The ox warble, which causes the lumps on the backs of cattle, worrying the animals and ruining the best leather in the hides, could be eradicated with a two or three year effort and at a cost of scarcely more than its annual damage to the livestock industry. The codling moth takes an annual toll of at least 10 per cent from the entire apple crop of the nation. It is absolutely dependent upon apples for its perpetuation. By taking advantage of an extremely injurious frost it could undoubtedly be eliminated from entire orchard areas. This would be especially easy of application in the western mountain valleys but might well be extended to the major apple growing regions of the continent. The boll weevil is the *bête noire* of the cotton grower. It is probable that control methods will be perfected to such an extent that it will be possible to keep this insect thoroughly in check if the expense of the operation is disregarded. When this time arrives it will be possible to consider its eradication from the cotton fields of the United States. The division of the cotton area into a number of zones has already been suggested but a method of controlling the weevils on the cotton along the margin of the zone will greatly reduce the possibility of spread and increase the probability of a successful outcome.

Hundreds of other opportunities could be suggested. Almost any insect pest or plant disease that is limited to a single host or presents a vulnerable point in its life history, extending through a sufficiently

long period of time to give the possibility of control, may be considered as a possible candidate for eradication whenever scientific investigation has progressed to such a point as to give the tools necessary for its accomplishment.

In summarizing it may be said that the research program of the Department of Agriculture is founded on the research individual and the utmost effort will be made to keep the outstanding research men in the Department, to obtain others as far as possible, to provide reasonable salaries and satisfactory publication and working conditions, to develop the possibilities of training, and in every way to establish the most satisfactory conditions for continued and productive research. While this is being accomplished the major effort will be to direct the work along the line of the fundamentals, to cooperate fully with states and other agencies in organizing for the attack on the problems now under investigation, to broaden the field of effort as rapidly as possible, and to inaugurate from time to time great national campaigns to eliminate pests or conditions whose presence has heretofore been a permanent overhead expense on the industries concerned.

WORK OF THE BUREAU OF CHEMISTRY

By C. A. BROWNE

Read at the Washington Meeting, December 7, 1923

As a text for this morning's program upon the relations of the Department of Agriculture to chemical industry, there is nothing more fitting than the motto upon the Department's official seal—"Agriculture is the Foundation of Manufacture and Commerce." When it is considered that man's necessary requirements of food, clothing and shelter are for the most part supplied by some branch of agriculture the truth of this maxim is too obvious to require demonstration. As a corollary of the Departmental motto it is equally evident that the division of chemistry, which ministers to the needs of agriculture, ranks first in importance among all branches of applied chemistry. Davy, Liebig, and Berthelot—to name only three great chemists of diverse nationality and genius—were, each of them, devotees to agricultural chemistry and wrote treatises upon the subject.

The first steps in the industrial development of this country were in rural technology. The earliest technical chemists were the agricultural pioneers. They made the first leather, sugar, malt, potash, and soap; they were the first to express oil from seeds, the first to employ dyes for coloring their homespun and the first to use the processes of salting, smoking, and drying for preserving their food. Later, with the diversification which comes from social advancement, there began to appear the special chemical industries of tanning, brewing, potash making, soap boiling, etc., which relieved the farmer of a part of his technical pursuits. But the transition to complete industrial specialization was gradual. There was a long cooperative period when the farmer took his homespun to the dyer, his hides to the tanner and his tallow to the soap boiler for making into the finished product in just the same way that he took his corn to the miller for grinding into meal. The unity of public opinion upon national economic questions, which resulted from the intimate personal contact of farmer and manufacturer during this cooperative period, was the one great factor which secured the establishment of

the protective system of Henry Clay in 1824, from which time chemical industry in America was given its first impetus and its first assurance of national support. It was only when extreme specialization in their respective fields snapped the bonds of union between agriculture and domestic industry that this harmony of public sentiment was destroyed and that the economic troubles of a later day arose.

Governmental inquiries into agricultural chemical industries were instituted long before the establishment of the present Department of Agriculture. As a source of public wealth these industries first stirred the interest of the Treasury officials and the earliest governmental investigations of a chemical character were made by that department. The notable investigation by Benjamin Silliman, for example, upon "The Cultivation of the Sugar Cane and the Fabrication and Refinement of Sugar," published by the Government in 1833, was conducted under the direction of Secretary of Treasury McLane.

Somewhat later these agricultural chemical inquiries devolved upon the Patent Office. In his report of January, 1843, the Commissioner of Patents suggested "the constitution of an agricultural bureau, or at least an agricultural clerkship, at a moderate expense to be drawn from the patent fund." This modest petition was granted by Congress and out of it 19 years later grew the present Department of Agriculture with all the scientific bureaus which are represented upon this morning's program. The heads of the Patent Office were fortunately men of broad vision and in reading their agricultural reports from year to year it is interesting to follow the increasing stress which was laid upon the relations of industrial chemistry to agriculture. In making a preliminary survey of the field, which the various agricultural bureaus were afterwards to take over, the Patent Commissioners performed a most valuable piece of work.

In 1862, when the present Department of Agriculture was organized, Dr. Chas. M. Wetherill became the first appointee to supervise its chemical activities. He was a technical chemist of some distinction, being the author of a treatise upon vinegar manufacture. His first published work for the Department was upon the chemical composition of American grapes. He also issued reports upon the manufacture of sugar from sorghum, sugar beet and sugar cane. But it was the analysis of fertilizers which chiefly engaged the atten-

tion of the first chemists of the Department, examinations of cereals, fruits, tanning materials, and other miscellaneous products being also performed so far as the limited facilities permitted. Those of you who knew the late Dr. Wm. McMurtrie may remember his saying that when he became chemist of the Agricultural Department in 1873 he had no one to help him in the analytical work, although one assistant was afterwards appointed. The salaries and equipment were of the same scanty allowance. The largest amount of laboratory space which Dr. McMurtrie ever had at his disposal consisted of only two small rooms with a closet and cellar. The Commissioner of Agriculture in his report for 1878 deplored the meagerness of this equipment. He emphasized the importance of chemistry to agriculture and petitioned for the establishment of a $300,000 laboratory with a working force of 20 or 30 chemists. But many years passed before this vision was realized.

The protection of the farmer against fraud in the purchase of fertilizers and the satisfaction of his curiosity as to the composition of whatsoever minerals he might happen to pick up, were regarded for many years as the chief function of the Department chemists. But approaching the late seventies there was observed a growing desire for the Chemical Division of the Department to help the farmer by determining the value of commercial cattle foods. The method which seeks to prevent fraud first in plant food, then in animal food and lastly in human food may seem contrary to reason, but such has been the sequence usually followed in the history of regulatory matters. The protection of the public against fraud in the purchase of human foods was not seriously considered by the Department of Agriculture until the question had been thoroughly investigated by Dr. H. W. Wiley after his appointment as Chief Chemist in 1883. The researches upon human foods, conducted at the Bureau of Chemistry during Dr. Wiley's administration, resulted in the passage of the Food and Drugs Act in 1906, the execution of the requirements of which became forthwith one of the chief functions of the Bureau. These new demands not only led to an enormous increase in the Bureau's equipment and personnel in Washington but they called into existence numerous branch laboratories to handle the work of inspection and analysis in the different sections of the country. It is from the year 1906 that the present enlargement of the Bureau of Chemistry's activities dates its beginning.

With this short sketch of the origin and development of chemical activities by the Department of Agriculture, we will consider very briefly a few phases of the Bureau of Chemistry's present work. The staff units of the Bureau of Chemistry, according to its present organization, are engaged along two general lines; law enforcement or regulatory problems and agricultural or technological problems. The heaviest of these in their demands upon men and money are the regulatory problems. The cost of the enforcement of the Food and Drugs Act during the past year exceeded $700,000, these and other expenses of the Bureau's work being defrayed by annual appropriations of Congress. The extent of the work performed in this field is partially indicated by the printed Notices of Judgment against violators of the Food and Drugs law, the bound volumes of which would more than fill the proverbial five foot shelf.

Various laboratories at the Bureau of Chemistry are engaged in this work of law enforcement in connection with the sale of foods, condiments, beverages, drugs, medicines, feedstuffs, and insecticides. With the recent passage by Congress of a Naval Stores Act, the Bureau will also have charge of law enforcement as it concerns the sale of turpentine and rosin.

The work of the laboratories engaged upon law enforcement does not consist, however, of mere analytical routine. Simultaneous with its regulatory operations the Food Control Laboratory is studying the baking properties of flour, the Microbiological Laboratory the rôle of micro-organisms in food manufacture, the Microchemical Laboratory the applications of micro-analysis to food and drug technology, the Cattle Food Laboratory the utilization of waste by-products for feeding animals, the Insecticide Laboratory improvements in the manufacture and application of insecticides, fungicides, and disinfectants, and the Tea Inspection Office the utilization of Ilex Cassina as a beverage. The same relationship between law enforcement and technical research is maintained in the other laboratories of the Bureau. Regulatory work and research are so closely allied that an intimate contact between the two must be maintained for the successful performance of the Bureau's activities.

The agricultural or technological problems upon which the staff units of the Bureau of Chemistry are engaged cover such a wide class of activities that only a hasty summary of them can be given. No technological investigations have attracted the attention of gov-

ernment chemists for a longer period than those relating to sugar and syrup. The sugar investigations published by Silliman in the thirties, by McCulloh in the forties, by Smith in the fifties, by Wetherill in the sixties, by McMurtrie in the seventies, and by Wiley in the eighties and subsequent decades were all performed under governmental support. It is but natural, therefore, that this class of work, which relates to the technical utilization of various sugar producing crops, should still be a leading subject of inquiry at the Bureau of Chemistry. In the same way chemical researches upon fruits, begun by Wetherill in the sixties, and researches upon leather and tanning materials, begun by McMurtrie in the seventies, are still being conducted in the Bureau's various laboratories. The same is also true of the technical investigations of early Departmental chemists upon fats, flour, paper, and other agricultural products. Such historic lines of inquiry will always be in order as long as new methods of research and new outlets of utilization are available. And if it is possible to judge the future by the past we may expect that, so far as new outlets for the technical utilization of agricultural products are concerned, the chemist will always point the way.

In several instances the Bureau of Chemistry has organized special research laboratories outside of Washington for the study of technological problems. A good illustration of this is the Citrus By-products Laboratory in California, which by developing methods for the utilization of culls and surplus citrus fruits has increased their value many times to the producer. This utilization of agricultural waste and surplus is one of the most important problems which confronts industry to-day and its solution is constantly engaging the attention of the Bureau of Chemistry. The development of industrial uses for waste sweet potatoes, the utilization of lesser known plant constituents and the technical production of furfural from corn cobs are other projects of this kind which the Bureau has under way. The industrial opportunities in this direction are many. As a specific example of an important unsolved problem may be mentioned the utilization of the lignin residue in wood, straw and other vegetable substances. This complex is fairly reactive but its successful economic conversion into dyes or other useful products is as yet unaccomplished.

The prevention of the losses which occur to agricultural products through the agency of micro-organisms, insects, fire, water, and other

destructive agencies presents another class of chemical problems equal in importance to those connected with the utilization of waste. The losses to the sugar industry from deterioration of the harvested crop between field and factory, or from deterioration of the raw sugar between factory and refinery, amount each year to many millions of dollars. The same is true of many other agricultural commodities. The Bureau of Chemistry has numerous projects under way in the field of loss prevention; among these may be mentioned the checking of the deterioration of paper and leather, improvements in dehydration and other methods for reducing the spoilage of foods, the prevention of dust explosions and the proofing of fabrics against damage by water, mildew and fire. A large number of unsolved chemical problems relate to this subject of loss prevention. The agricultural interests of the country suffer millions of damage each year from spontaneous combustion but the chemical mechanism by which a mow of hay or a car of stock-feed catches fire is not as yet explained. Less spectacular, but more generally destructive, is the deteriorative effect of atmospheric oxygen upon butter, lard, paper, leather, and other commodities.

The research work of the Bureau of Chemistry, in many of its activities, is cooperative in character. Collaborative investigations are conducted with other Bureaus of the Department and also with such organizations as the Association of Official Agricultural Chemists and the Committee for revising the U. S. Pharmacopœia.

The Bureau of Chemistry by working in cooperation with various branches of the food industry has in many instances pointed the way to improvements in the purity and cleanliness of manufactured products. The shortages of sugar, fats and other materials during the recent war caused an unfortunate lowering in the character of certain manufactured foods and the temporary debasement then allowed was seized upon by unscrupulous manufacturers in many countries as a legitimate excuse for continued inferiority. It is an important duty of the Bureau of Chemistry to determine how far the standards of our food products shall be influenced by such economic factors as deficiency of supply and how far the demands of a selfish commercialism shall be resisted.

In measuring the growth of the Bureau of Chemistry's activities, since Dr. McMurtrie entered upon his solitary position just half a century ago, one is tempted to inquire as to the trend of developments during the next 50 years. With relation to the consuming

public, which is largely urban, the Bureau of Chemistry's greatest service will lie, as at present, in the work of law enforcement. The Bureau's regulatory operations, controlling as they do the purity of the basic necessities of life, are bound to grow both in volume and importance.

With relation to the producing or agricultural public the Bureau will unquestionably perform its greatest service in the field of chemical technology. American agriculture, through the increased use of machinery, motor fuel and other technical requirements, is becoming more and more an industrial pursuit and the farmer is taking a renewed interest in the practical applications of chemistry to his needs. When a century ago the farmer, as previously mentioned, surrendered the manufacture of his raw materials to people with whom he had no ties of cooperative need, he was obliged to sell his produce for whatever the purchaser chose to pay. As a result of this economic mistake agriculture ceased in many localities to be any longer remunerative. While it is inadvisable that the farmers of the country should attempt to manufacture all their own raw materials there is much that they can accomplish by cooperative effort, when the situation demands. The farmer necessarily must always sell a considerable amount of his produce. With the disappearance of the close sympathetic relations that existed a century ago between agriculture and industry, the farmer must now establish grades and standards for his raw materials in order that a fair adjustment may be secured between himself and the manufacturer.

In the discharge of its duties to both producer and consumer, the Bureau of Chemistry is rendering effective service and it is in the enlarged opportunities of this double field that future progress must be made.

Discussion

Mr. Chas. Wadsworth: I should like to ask Dr. Browne if he would give us a word about the relation of the sugar work of the Bureau of Chemistry to the sugar work of the Bureau of Standards.

Dr. C. A. Browne: The question of the duplication of work by different Governmental Bureaus is generally misunderstood. As a rule it may be stated that the subjects in which the Bureau of Standards is most interested relate to standardization. While I have not visited the Bureau of Standards recently and so am not able to say definitely what researches are being conducted there upon sugar, I can state that one of the lines of work in which that Bureau is actively

engaged relates to the standardization of polariscopes, which are used for sugar testing, to the fixing of the physical constants of sugars, and to other work of a similar nature. These subjects are not investigated by the Bureau of Chemistry, which concerns itself principally with the agricultural chemistry of sugar production; with questions of sugar technology, such as clarification; with the utilization of molasses and the manufacture of syrups; and with the standards of syrups, molasses and sugar as articles of food.

President Howard: I should like to ask Dr. Browne about what the Bureau is doing and what position is being taken by the Government in regard to preservatives used in the so-called soft drinks of today. Benzoate of soda we used to hear a good deal about as objectionable. Is that allowed now?

Dr. Browne: It is allowed as a preservative, but has to be declared with its amount on the bottle in the case of food or substances of that kind.

President Howard: Have you made any studies recently as to physiological effects of the preservatives used?

Dr. Browne: No, nothing has been done on that since Dr. Wiley made that investigation, and also the Referee Board of which Dr. Chittenden, Dr. Remsen, Dr. Herter and Dr. Long were members, fifteen years ago.

President Howard: There is such an enormous consumption of those things today that it seems it might be a profitable field for your investigators. I notice very many of these drinks radically affect the mental alertness of people with whom I have talked, making them sluggish, and indicating that there was some preservative present in improper proportion.

Dr. Browne: It may be due to other substances of which many are included.

Dr. Olsen: Is the Remsen Board report still available?

Dr. Browne: It was published as Report No. 88 of the Department of Agriculture, and can be purchased from the Government Printing Office.

Dr. Olsen: That was a very important report. I read it all the way through, and they certainly went to the greatest length in their investigations. They used very considerable quantities of those preservatives every day and noted the physiological effect and the evidence seemed to me very conclusive after the investigation that benzoate of soda had practically no ill effects.

President Howard: It may be due to other ingredients, but it seems to me that that branch of food consumption has changed so radically since the 18th Amendment came in that it is something which the Bureau ought to study in the interest of public health.

Mr. E. L. Wilson: We all recognize the tremendous value of the Bureau of Chemistry in work of this kind, particularly in pointing out the deleterious substances in our food, and of course the manufacturers of food are anxious to cooperate with it, and have it investigate their foods and preparations, so that they may conform to the standards of the Bureau. The Bureau through the press, has a very powerful means of advertising what it is doing, and the public naturally reads about these investigations and perhaps is governed by them to the extent that it should be. There is one thing about these investigations, however, that I think might be improved. That is, that the Bureau could sometimes use the press to inform the people that after investigation it has found that a manufacturer of food has conformed to its standards. Lots of times the effect on the public, by having the manufacturer brought before the Bureau for the investigation of his materials, is to work great harm to the manufacturer, and this publicity could be given to the result after the Bureau has determined that the particular material it is working on is perfectly all right. This might relieve the manufacturer of a great deal of trouble in advertising the fact that he had been brought before the Bureau, but that his preparations were found to conform to the standards of the Bureau. This happened in one case I know of where a great deal of harm resulted. If the Bureau could use some of this publicity, to show the results of their investigations, it might be a decided advantage.

Dr. Browne: I should like to say in connection with that, that the Bureau of Chemistry would like very much to send out in addition to publishing the names of the violators of the Food and Drugs Act, the names of the manufacturers who conform to it, but the expense of doing that would be almost prohibitive, and we are unfortunately very much limited in the appropriations, in doing what Mr. Wilson has requested.

Dr. J. C. Olsen: Is the information that you have found them O. K. available?

Dr. Browne: This knowledge might be available if all the products of all manufacturers could be investigated. Such a board examination is, however, impossible, owing to our limited appropria-

tions, and it has not been thought desirable, therefore, for the Bureau to give out the names of brands of products which are found to conform with the requirements of the law, since it might result in the unfair advertisement of the products of certain firms at the expense of others which might be equally meritorious but which had not been examined by the Bureau.

Dr. C. L. Reese: Couldn't that trouble be obviated by saying that other manufacturers have been found all right?

Dr. Browne: That, of course, is understood, since we only bring out the names of the violators.

Dr. Reese: A statement that no other violators of the law were found would cover your point, wouldn't it, Mr. Wilson?

Mr. Wilson: Yes, The press is very prone to take up any such matter and broadcast it throughout the nation, and everybody will read the story of the manufacturer who has been hailed before the Bureau of Chemistry for examination. Everybody is then supicious of the product. When the Bureau makes the investigation it clears the manufacturer, but the public press does not publish that fact, and the public does not know about it. I am speaking now of a nationally manufactured and distributed product, used in every household. People reading the published statement, that the manufacturer is called before the Bureau in Washington concludes that something must be wrong with the product. This fact is advertised by other manufacturers of rival products. If the Bureau would use the public press to give the results of their investigation, then it would certainly clear the conscientious manufacturer of disgrace.

Dr. Browne: I should state in this connection that the only information which the Bureau gives out about the products that it examines is contained in the official Notices of Judgment under the Food and Drugs Act, which are limited to those cases in which a court decision for adulteration or misbranding has been rendered. Notices of citation and of summons to hearings are not given out for publication by the Bureau.

President Howard: I think the Bureau might obviate the question of expense by writing a letter to the manufacturer in question, which the manufacturer would be permitted to publish, and then let the manufacturer in question pay the expense of publicity if he wants any. You do that very thing, I presume, in rendering your decision. Are there further questions?

(Discussion closed.)

FOREST PRODUCTS IN THE CHEMICAL INDUSTRIES

By L. F. HAWLEY[1]

Read at the Washington Meeting, December 7, 1923

Many people do not realize the importance of the forests to chemical industry nor see the necessity for chemists in the Forest Service. To an audience of chemical engineers many connections between chemistry and forestry will occur, but it may be of interest as an introduction to give some of the more important connections in detail and simply to mention others of less importance.

The largest chemical industry using wood as a raw material is the pulp and paper industry. In 1922 about 7,000,000 cords of pulpwood were consumed in the United States and Canada, of which 65 per cent was used by the chemical processes. This industry is also very particular about the species of wood it uses. Pulpwood consists chiefly of two or three species; spruce, balsam, hemlock, and aspen make up 80 per cent of the total.

There are several important chemicals which are produced largely from wood by the wood distillation process—acetic acid, acetone, methanol, and formaldehyde. Recently the first two have been made from other sources, but wood is still the only commercial source of methanol and formaldehyde. Over 1,000,000 cords of hardwood are used yearly for distillation.

The tanning industry depends largely on the forests for tanning agents. Chestnut wood and hemlock, chestnut oak, and tan oak barks are the native forest products most used for tanning; but others are imported, such as quebracho, mangrove, and myrobolans; and still others of lesser importance are collected in this country, such as sumach and osago orange.

Turpentine and rosin are forest products of great importance in the chemical industry. This country produces about three-fourths and consumes nearly one-half the world's total of these products, which are so important in the paint, varnish, soap, and paper industries.

[1] In Charge Section of Derived Products, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture.

There are also a large number of less important chemical forest products: cedar wood oil, cedar leaf oil and other needle oils; Canada balsam and Oregon balsam; various medicinal barks, such as cascara sagrada and slippery elm; galactan, which has become a commercial source of mucic acid; and various sugars and gums. Our temperate zone forests are not so prolific in these miscellaneous chemical products as are the tropical forests, but the list just given is impressive and other products may be developed.

Wood as a structural material is also of importance in chemical industry, since it is resistant to the chemical action of weak acids and can be used in tanks, towers, and pipes in contact with chemicals which might corrode iron or steel.

Enough has been said to show the value of the forests to the chemical industries and to account for the interest which the chemical industries should take in forest conservation. It might be of interest to describe some of the methods employed by the Forest Service in promoting forest conservation. Instead of giving the silvicultural side of the program it is probably better, with an audience of chemical engineers, to show how chemical research is used in forest conservation.

Some time ago it was decided that increased efficiency in the utilization of forest products was a very important part of any forestry program, and the "Products" work of the Forest Service was the result. This work on better utilization of wood is divided into seven principal fields, the purpose in each case being: *Research for better utilization.*

1. The use of less wood in construction work through more complete knowledge of strength and grades and design.
2. Reduction of waste or degrade through better methods of production, particularly in drying.
3. Higher yields (or in general greater efficiency) in chemical processes using wood as a raw material.
4. Use of new and less costly species.
5. Use of waste wood instead of more valuable wood.
6. Waste wood utilization by new methods.
7. Prevention of decay in wood.

The first two of these fields are purely mechanical and physical, and no attempt will be made to elaborate on the research which has been carried on to bring about these results, although it has been im-

portant and successful. In all the other fields chemical research has been employed (in the last three of them chemical research exclusively), and some examples of the work and the results will be given.

In order to bring about the utilization of new, cheap, and plentiful species as substitutes for the more expensive species a fairly complete study has been made of the paper-making qualities of nearly a hundred American woods. The yields and quality of the pulp made by the soda, sulphate, and sulphite processes have been determined, and in several cases satisfactory substitutes have been found for the common pulpwood spruce in making both sulphite and sulphate pulps.

Many hardwoods have been distilled to find the yields of acetic acid, methanol, and charcoal; and it has been found that several species give as good yields as the beech, birch, and maple which had been used almost exclusively since the foundation of the industry in this country.

The development of the use of waste wood in place of wood prepared especially for a certain process is more a process of education and persuasion than one of research. For instance, the use of spruce slabs by pulp mills in place of the round or split pulpwood is difficult to develop, although from the chemical standpoint the slabs are certainly as good. It has been shown by experimental work that the slabs (including bark) of certain species of hardwood give at least as much alcohol and acid as the heartwood. Such information ought to lead to the utilization of more mill waste.

Certain finely divided forms of waste, such as sawdust, can not be used the same as cordwood for chemical purposes even though they have the same chemical composition. For instance, sawdust can not be destructively distilled in the same kind of apparatus that will handle cordwood and a chemical pulp made from sawdust is not suitable for paper making on account of the shortness of the fibers. These examples show the need of investigation to adapt waste materials to other uses.

The production of higher yields in any chemical process using wood as a raw material is a direct saving in wood consumption, and many of our investigations have been directed toward this end. In the hardwood distillation industry a modification of firing procedure has been introduced as a result of our experiments, which gives 5 to 10 per cent increase in the yields of the chemical products. More recent work has shown the possibility of increasing the alcohol yields

by at least 50 per cent by treating the wood with as little as 0.5 per cent sodium carbonate before distillation. This has not yet been tried on a commercial scale, but arrangements have been made for trials in the near future.

Many refinements in cooking procedure have been studied to increase the yield or efficiency in soda, sulphite and sulphate pulp manufacture. It has been shown that in all the chemical processes for making pulp the rate of heating the digester has a great influence on the yield of pulp, which can be increaced from 10 to 20 per cent by following a regular heating schedule. A large number of experiments have shown the effects of time of heating, concentration of chemicals, temperature, and pressure. An insight has been gained into the chemical reactions proceeding during the pulping operation, transforming this operation from a "rule of thumb" to a precise chemical basis. The manifold uses of wood pulp continually create new problems in the study of the pulping process, especially as wood is the only cheap and plentiful raw material at present which can be used for paper making.

The previously mentioned researches have been in connection with industries already in commercial operation. In order to increase the utilization of certain kinds of waste, such as softwood sawdust, it has been necessary to develop new methods or further to investigate suggested methods which had not been sufficiently successful to use large quantities of waste. Much new information has been gained on the processes of making cattle food and ethyl alcohol from softwoods by hydrolysis with dilute acids, and it is hoped that the work now under way may result in the successful commercial manufacture of both of these products from wood waste.

Some of our experimental work has resulted in the utilization of waste wood from western larch, through the extraction of the galactan found in this wood and the manufacture from it of galactose and mucic acid. In a similar manner our studies of the coloring matter in the wood of osage orange have led to the successful commercial manufacture of a dyeing and tanning extract from waste wood of that species. Although waste utilization methods have been found for certain species like these, it has been because extractives of unusual character were found in the wood. We have not yet developed any chemical method of waste utilization suitable for all forms and species.

By far the greatest preventable destruction of wood products is decay. The prevention of decay is therefore potentially the most important factor in lessening the drain on the forests. The preservation of wood against decay has been a commercial process for many years, but there is still much to learn about the process. Much wood is still used without preservative treatment in situations favorable to decay.

Tests of preservatives and methods of injecting them into wood have been studied. Some species are comparatively easy to impregnate, while others resist the penetration of preservatives and it has been necessary to develop treating methods for each species which will give the penetration and absorption of preservatives necessary to provide adequate protection.

Railway ties, posts, poles, and piling, dock and other structural timbers are coming more and more to be treated with preservatives to prevent decay. Marine structures are also being treated to prevent borer attack. Service test records on installations of both treated and untreated timbers are kept. Periodic inspections add to the bulk of authentic information, making it of great value in estimating the probable durability of structures and in specifying the preservative or method of application best suited for a given construction.

Coal-tar creosote and zinc chloride are the two most widely used preservatives, but others have been found that are good for special uses.

These brief statements give a general view of the importance and the varied character of the chemical work of the Forest Service. One other point not touched upon should be emphasized. Although our research work is industrial research and industrial application is always the end in view yet, like other large industrial research organizations, we have not hesitated to devote a considerable proportion of our effort to fundamental scientific research. We have felt that the more information we have on the general subject of the chemical composition of wood, the more rapid and successful will be our specific investigations on chemical methods for utilizing wood. We have therefore kept in progress projects on the chemical composition of wood and especially one on the analysis of species, both heartwood and sapwood, and we now have a compilation of data on this subject far in advance of that available elsewhere. These data

have not only been of much indirect and more or less intangible assistance to our more practical research projects or to industrial operations, but have directly resulted in commercial application in the cases of western larch and osage orange woods, as already mentioned.

In connection with the general study of wood preservatives we have also carried on considerable fundamental scientific work on such seemingly trivial and impractical subjects as "Why and how does a wood preservative preserve?" and "What is the relation between chemical composition, physical characteristics, and preservative value?" Here again the information obtained has not only been of indirect assistance to the industry, but lately, when a new preservative for very special use was required, it was possible from theoretical considerations alone to recommend a new, cheap, and satisfactory mixture.

It is understood that this meeting was held in Washington largely for the purpose of studying the chemical work of the government departments and that these papers are mainly preparation for later inspections of the laboratories. Unfortunately, you will not be able to do this in the case of the work just described since our chemical research is carried on at the Forest Products Laboratory, Madison, Wisconsin.

Discussion

Dr. Chas. L. Reese: I understand you to say that you are still doing work on the production of alcohol from wood. One of the main difficulties in regard to that manufacture is the cost of transportation of sawdust in the large quantity required to manufacture alcohol. The largest plant built in this country is the one which we operated at Georgetown, South Carolina. We had an ample supply of sawdust for a while, and the plant operated successfully, but when the supply of sawdust gave out because the saw-mill shut down we had to shut the alcohol plant down, and we had to abandon the project because we could not get sawdust enough to keep the plant running at full capacity. We could not afford to transport and pay freight on sawdust. That seems to be the great difficulty about manufacturing alcohol from sawdust. It will not stand the freight. If you can produce alcohol in much larger quantities from sawdust, it might solve the problem.

Dr. Hawley: The present process will work when you can obtain sufficient sawdust. If you can make it a little more productive

it might be practical to transport part of the sawdust. In only a few cases is it possible to locate a plant where it will be fully served by sawdust at the point of use.

Dr. Reese: Is there any method of getting rid of the so-called winged ant which eats wood? That is an insect that comes out of the ground or the wood, and runs around and does not seem to fly very much. In a few hours it disappears. I have seen a floor in a room as big as this completely destroyed by these insects.

Dr. Hawley: That is something that the Bureau of Entomology is working on now. They are now studying what it is that the ants find in the wood to live on, and what can be put into the wood to preserve it.

Dr. Reese: That is interesting. I should like to know how to get rid of those ants, white ants, if that is what they are called. I tried formaldehyde, but that was disastrous to my plants.

Dr. Hawley: I believe there are certain species of wood which are fairly resistant to white ants. I am not certain about that, but I know some work has been done recently, and I believe that cypress wood is about as resistant as any in this country. Certain tropical woods are completely resistant, but cypress wood is reasonably satisfactory. The Bureau of Entomology has some men working on that, who can give you information.

Dr. J. C. Olsen: The Seaman process for producing alcohol from sawdust was operated in Virginia for a while, but they had to discontinue also for exactly the same reason, that they did not have a local supply of sawdust. They spent a lot of money on the Seaman plant and got it to perform successfully, but they could not pay freight on the sawdust to bring it to the plant.

Mr. James: Have you any information to make public at the present time on the use of low temperature coal tar as a wood preservative?

Dr. Hawley: We have just started a little work on that. It is impossible to make a laboratory study of a wood preservative and show exactly how it will act. That is something that we attempted to do, to find some sort of a rapid test for wood preservatives, but up to the present time we have been able to develop nothing of that kind. There are some indicative laboratory tests, such as corrosion, toxicity, and volatility, but we can not say until we have put that material into a railroad tie and put it under actual service condi-

tions. The promise for low temperature creosote seems to be very good.

Mr. James: What is the minimum of time in which such a test could be made?

Dr. Hawley: In certain cases and with certain woods in a couple of years, but even in five years decay might be negligible. I should say five to seven years is the very minimum time for getting certain results.

Dr. Reese: If you will permit me, I will tell you the rest of that story. The formaldehyde did not kill the ants [laughter].

Dr. Ball: That is one of the peculiar things of nature. Formaldehyde is a good fungicide but absolutely worthless as an insecticide.

(Discussion closed.)

FERTILIZERS AND SOIL FERTILITY

By MILTON WHITNEY[1]

Read at the Washington Meeting, December 7, 1923

During the last years of available records before the disturbances caused by the World War, Germany was using 188 pounds of commercial fertilizers per acre of land in crops, Great Britain was using 162 pounds, France 79 pounds, Italy 77 pounds, Spain 31 pounds, and Russia in Europe 6 pounds. The United States as a whole was using 40 pounds of commercial fertilizers per acre of land in crops.

The greatest intensity of use in this country was in the Atlantic Coast states from Maine to Florida, where in each one of the states bordering the Atlantic Ocean, with the exception of Delaware, the intensity of use ranged from 150 pounds per acre of land in crops in Maryland to 345 pounds in Florida. The great proportion of this fertilizer was used in the potato districts of Maine, for the truck crops of the whole Atlantic Coast, on the high-grade wrapper tobacco and the cigarette tobaccos, and on cotton in the South Atlantic states.

The cotton crop is practically unfertilized west of Alabama and the commercial crops of wheat, corn, oats and hay are produced practically without artificial fertilizers.

These staple crops, cotton, corn, wheat, oats, and hay, each occupy 30,000,000 acres or more and together occupy 87 ½ per cent of the total crop area of the United States.[2] As the bulk of each of these crops is grown where the others are hardly produced in quantities, we can not be said to have the conditions for a national rotation system on the soils of the United States. We talk about rotations as one of the important methods of maintaining productivity but in the country as a whole this valuable method can not be said to be practiced in a systematic and general way. It has certainly not attained that general and systematic use that is given to it in the countries of northern Europe.

If we aim to increase the intensity of fertilizer use to anything like the practice in the north of Europe, which seems highly desirable

[1] Chief, Bureau of Soils.

[2] Farmers' Bulletin No. 1289.

to bring the yields per acre of our staple crops up to their standards, we shall require four or five times as much fertilizer material as we are now using. The question arises as to whether we have available sufficient material or if it may be obtained.

Approximately half of the fertilizer we use consists of acid phosphate. For this we have abundant supplies of raw material in this country to take care of any increase which may be necessary. With our present methods of treating phosphate rock with sulphuric acid we throw away on the dumps at least 60 per cent of the phosphoric acid that we mine and we reduce the concentration of phosphoric acid from 32 per cent in the rock to 16 per cent in our finished product. As a chemical engineering problem this will certainly appeal to you as a wasteful system.

The Bureau of Soils has been working on methods of separating the phosphoric acid from the lime in the electric furnace and now is attempting to cheapen the cost by the use of fuel fed furnaces. Both of these methods are being adopted by commercial concerns. This process in general uses will give us a fourth acid for various commercial purposes relatively as cheap as sulphuric acid and cheaper than hydrochloric and nitric acids and will give in many commercial industries by-products which will be of value to agriculture, instead of waste products which have to be disposed of at considerable cost.

The domestic supply of the most expensive constituent of our fertilizers, nitrogen, is inadequate for our present needs and still more so for our prospective needs. Approximately one-third of the nitrogen of our fertilizers is supplied by the Chilean nitrate of soda. The amount of this which could be imported is large but as you all know there are objections to the exclusive use of this salt in our present fertilizer mixtures and there are objections to relying upon a foreign source of supply so distant from our markets.

The most important domestic source of nitrogen is ammonium sulphate from by-product coke ovens. The supply of this material depends upon the markets for coke and we are producing somewhere near the rated capacity of the industry at the present time.

The other principal domestic sources of nitrogen are cotton seed meal, slaughter house tankage, and relatively small amounts of dried blood and fish scrap. These organic ammoniates if properly prepared are counted as low analysis fertilizers, but are among the most concentrated feed stuffs that we have. Cotton seed meal with seven

per cent of nitrogen is low grade compared with 15 or 16 per cent in nitrate of soda and 20 per cent in ammonium sulphate but, with its 40 per cent of protein, cotton seed meal is a high grade feed stuff and is being used more and more for that purpose.

The world has come to look to the nitrogen fixing methods as offering the only solution for the increasing demands for nitrogen compounds for use in agriculture.

Until the necessities forced upon us by the European War this country had practically no domestic supply of potash. The potash supplies of Germany and of France could undoubtedly meet all needs for this constituent for a very long time, but this country has twice in recent years seen the danger of depending upon a foreign supply of potash. The Bureau of Soils after a thorough and searching investigation has found no workable surface supplies of either nitrates or potash salts in this country. The Geological Survey is investigating certain deep deposits of salt which give indications at least of the possibility of finding workable deposits of potash salts at considerable depths in certain parts of our country. The Bureau of Soils has shown the possibility of securing an adequate supply of potash from the giant kelps of the Pacific Coast, from the flue dust of the cement mills and blast furnaces and from other sources provided certain industries can be depended upon to conserve the volatile products of their furnaces and provided economical methods can be worked out to produce the potash from other materials at sufficiently low costs. The Bureau is working on all these methods to assist in working out the problems of economical production of potash from such material as is available.

With ammonia gas as the principal product of the modern fixation methods, with liquid phosphoric acid as the product of the modern method of treating the phosphate rock, we have at once the opportunity for putting the fertilizer industry on a strictly chemical basis and by using mono-ammonium phosphate with ammonium nitrate for boosting the nitrate content and with potassium phosphate and potassium nitrate for boosting the potash content of producing concentrated fertilizers without filler and containing no waste material. Furthermore in requiring no by-products it would be independent of other commercial industries.

As chemical engineers you can see the possibility and the desirability of absorbing the ammonia from the by-product coke ovens in

phosphoric acid rather than in sulphuric acid for fertilizer use and you can also see that the muriate of potash imported from Germany can just as well be broken down by treatment with phosphoric acid with the production of hydrochloric acid which would be paid for by other industries and which serves no real purpose in a fertilizer mixture.

The salts, ammonium nitrate, ammonium phosphate, potassium phosphate and potassium nitrate can be mixed in any proportion without decomposition. The mixture would be readily soluble in water and could be applied as a spray or as a solution or could be applied directly to the soil with or without mixing with sand, peat or other filler.

The fertilizer industry is coming to see the advantage of more concentrated or high analysis mixtures, although they do not as yet cordially endorse a fixed nitrogen program and the change in the methods of producing phosphoric acid, as they have not been able to see how fixed nitrogen products that up to this time have been produced can enter into their present system, and they realize that the change in the method of producing phosphoric acid to adapt it to the most efficient utilization of the basic product of the fixed nitrogen plants, namely ammonia gas, would mean a very decided modification of their present plants and of their present method of manufacture. As chemical engineers I think you will see the desirability, especially in view of the increasing amounts of fertilizer this country is going to use in the future, of reorganizing the fertilizer business on a strictly chemical basis instead of leaving it as the sort of scavenger industry it has been in the past.

The long-time plot experiments at Rothamsted appear to indicate that on their soils, under their climatic conditions and with their cultural methods, crop rotations without fertilizers increased and maintained their yields about as well as the application of complete fertilizer mixtures on crops continuously grown; that where rotations and complete fertilizers were both used on the same plots the increase due to the effect of rotation is about equal to that of the fertilizer.

The long-time plot experiments of Ohio indicate that the average increase of corn, oats, and wheat, due to rotation without fertilizers, is 40 per cent less than the effect of fertilizers without rotation and that where both methods are used, that is fertilizers and rotations,

the increase of the crop is nearly equal to the sum of the increases obtained from each method separately used.

The results of all of these experiments indicate that after from 5 to 15 years the average increase attains a maximum from which point onward the average increase is barely maintained or more or less sharply declines.

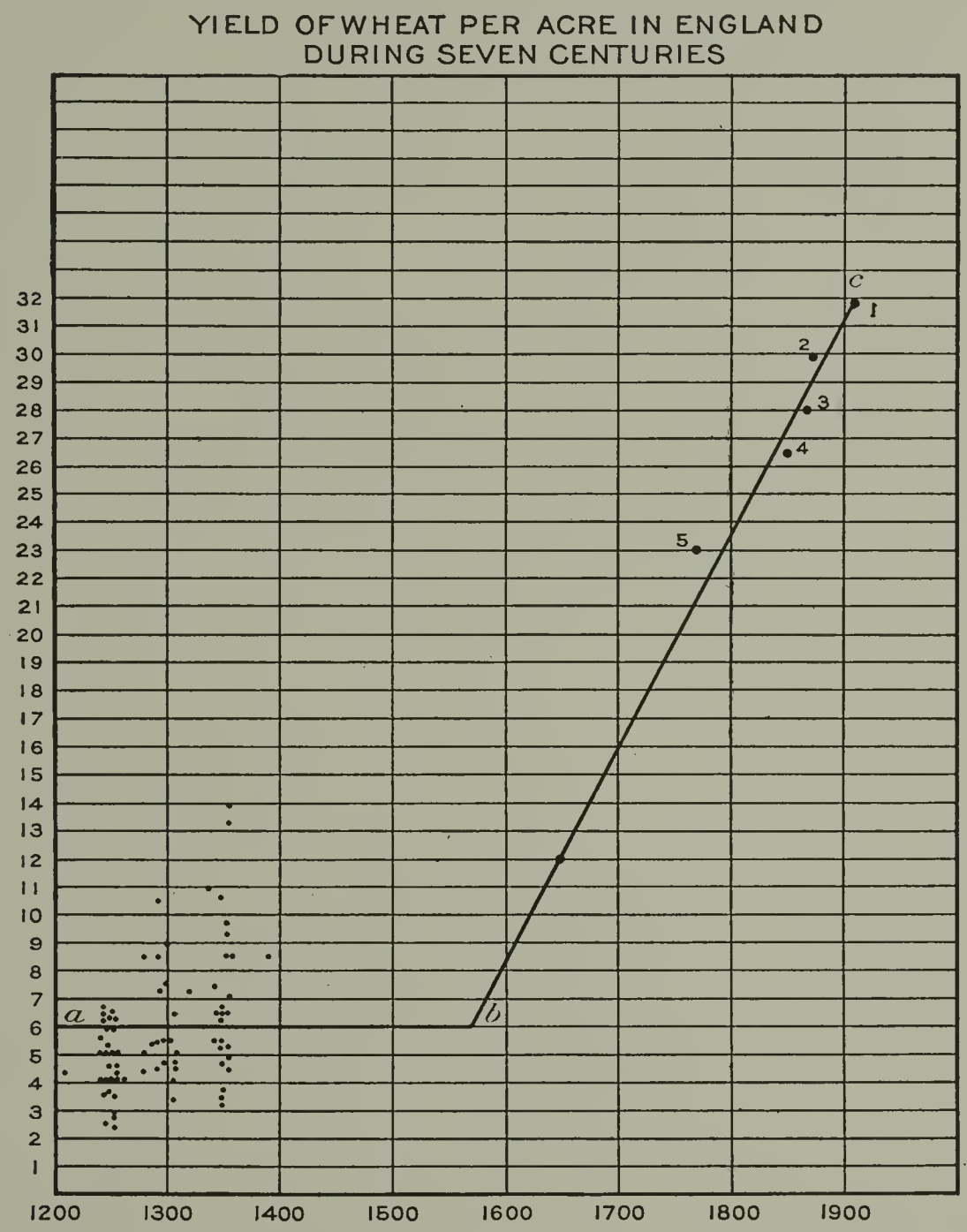


FIG. 1.

The long-time plot experiments with fertilizer mixtures which are laid out to be followed without variation for a long period of years have in no cases developed maximum average yields which are not uncommonly attained by our best farmers, and do not apparently continue to increase throughout the years of experiment, indicating

that some changes must be made during the life of the experimental period if we hope to attain a continuous increase in crop. There is an indication, therefore, that to secure a continually increasing yield or to secure maximum yields there are factors necessary to be controlled other than a rigid rotation system or a rigid application of fertilizers. The progress made by the English farmer, which is discussed in the following paragraph, may give some suggestion as to the reasons the fixed fertilizer plot experiment has failed to keep pace with the practice of the best farmers.

An exhaustive study of the yield of wheat per acre in England during the past 7 centuries indicates that under the medieval system of agriculture prevailing under baronial and monastic rule, where inclosures were prohibited by law and enforced by military power and ecclesiastical dogma, the level of the yield of wheat was around six bushels per acre. The fall of the baronial and monastic powers, the growth of industries and of urban population, the opportunity for individual effort and competition, the introduction of clover and tame grasses, of turnips and potatoes, the introduction of rotation systems, the better selection of seed, the improvement of livestock, the increased use of manure, the exclusion of weeds through better methods of tillage, the introduction of guano and recently of commercial fertilizers, have all contributed to cause a gradual increase in yield per acre at the rate of about eight bushels per century until now an average yield of 32 bushels per acre has been obtained with all indications that the yield per acre is continuing to rise with better methods and more systematic management of the soil.

These are matters which I consider necessary to bring very briefly to your attention as chemical engineers in order that you may at least get a glimpse of the development of the uses of the soil.

Discussion

Dr. C. L. Reese: I should like to ask a question which has been brought to my mind by experience, as to the effect of cultivation of the soil, as against fertilizer.

Dr. Whitney: That is recognized as one of the slack methods of English farmers under medieval conditions. They had to live in villages for defense; their fields were scattered, their farms were changed from year to year; their farms were narrow fields half to three-quarters of an acre, separated from the next field by

a balk, but no one man had a continuous succession of those fields. He had to go long distances from one plot to another. They were away a great deal. They had to defend their patrons. They had to rush their cattle into the mountain fastnesses for protection. The weeds were something appalling. They often gave up a field because it was so full of weeds. It was Tull that gave the great impetus throughout northern Europe to the more efficient cultivation of the soil. He started really the more efficient cultivation, and they recognized it, and it is recognized throughout the world that that is the basic thing in cultivation.

Dr. Reese: The reason that I mentioned this is that we had a project for cultivating camphor trees in Florida. It is a very sandy soil and in order to determine what fertilizer or combination of fertilizers was a proper one for camphor trees we set out a triangular system and fertilized it using three different kinds in various ways, and covered all the possibilities by using these three fertilizers to determine what was best for the tree. The camphor trees were planted in rows about 10 or 12 or 15 feet apart, possibly 20. And the custom on the plantation was to cultivate four or five feet on each side, or a few feet on each side of the camphor tree. I happened to go to the plantation to inspect it at the time they were making this fertilizer experiment, and I was most interested to find that in that part where the cultivation was carried on between the trees, no weeds being allowed to grow, although nowhere were weeds allowed to grow near the plants, the trees grew better than in any other section where fertilizer was used. That impressed me seriously with the importance of cultivation.

Dr. Taylor: It is a fundamental thing.

Dr. Browne: Did you try cultivation plus fertilization?

Dr. Reese: I don't think at any point where they used fertilizer did they cultivate all through.

Mr. Hugh K. Moore: Perhaps in addition to Dr. Reese's remarks I might say that we are starting big operations in cultivating peanuts in Florida. We were told by Government authorities that Florida was not fit soil for peanuts, but during the last four years we have been making experiments on a large scale. We saw, however, that when you turn that soil over and leave it for a year to oxidize we get wonderful yields of peanuts, and we are now developing the proposition on a large scale, and have been doing that for

four years. If you turn it over and let it ozidize it produces wonderful yields of peanuts very rich in oil.

PRESIDENT HOWARD: I should like to ask Dr. Whitney if he has gathered together any data on the method of agriculture in use in Russia prior to the war. The method that you speak of as being in use in medieval Europe was used regularly, as you probably know, in Russia, up to the time of the war. Then the rotation of crops was insisted upon and carried out as a part of the Communistic policy. In Imperialistic Russia you have the most Communistic civilization that you can hope for, with a village located in the center of a large tract of land divided into three portions, one portion lying fallow, one portion producing the first crop, and one portion the second crop. Each family in the community would have the right to work a certain piece of land, but might have to go one day three miles due west to work his little plot there, and the next day two miles east to work his little plot there. It did not work out satisfactorily because they did not own the land and none of them wanted to do work which somebody else would profit by later on. But there was one thing for which Russia was quite noted, and that was the accuracy of its statistical data. It had very accurate statistics on all these matters, and as they have been preserved you might get some valuable data for recent years on that type of agriculture, which was very similar to that employed in medieval Europe.

PROFESSOR A. W. SMITH: I should like to ask whether there is anything being done with the vast deposits of phosphates in Tennessee, below the grade you mention? The last I knew, they were discarded, but I wondered if there had been any method developed recently for recovering that large amount of phosphate?

DR. WHITNEY: We have it in mind. It is impossible to use it with the former method, but with our more modern methods we believe it can be used, and very successfully. Under these modern methods, where we briquette our material, it is undesirable for us to use the high grade rock. and we prefer to use the run of mine rock which has a sufficient binder to hold it. The material that you speak of is spread over very large areas, but we do not think that the time has come yet for encouraging its use in a commercial way. However, we have it in mind.

(Discussion closed.)

HOW CHEMISTRY HELPS SOLVE LIVESTOCK PROBLEMS

By DR. JOHN R. MOHLER[1]

Read at the Washington Meeting, December 7, 1923

To the lay mind the relation of chemistry and of chemical engineering to the livestock industry may appear rather remote. When we think of chemistry we usually picture an industrial enterprise. Consequently, a discussion of chemical engineering that relates to livestock production on farms and ranches and that has to do with dairying and poultry raising may provoke some curiosity.

Chemistry Important in Feeding

But consider, for instance, the question of feeds. Examine almost any sack of commercial feedstuffs and you will see either on the sack or on the tag the chemical analysis of the ingredients. Livestock owners read the analyses and study them. They understand that protein, carbohydrates, fat, fiber, and other ingredients have their proper places in rations for farm animals and purchase feeds accordingly. In dairying, milk and cream commonly are marketed on the basis of their fat contents, as determined by a chemical test.

I mention the foregoing examples not because they are new, but rather because they are familiar and commonplace. They have become so commonplace, in fact, that we are inclined to take the relation of chemistry to livestock for granted and thereby possibly lose contact with new developments in the work.

Arsenic Wins an Empire from Ticks

The project of tick eradication illustrates the dependence of livestock owners on applied chemistry in placing their business on a higher plane. The cattle tick is an insect pest transmitting Texas fever, and for years it caused a loss close to $40,000,000 annually. The method of eradication involves dipping of cattle in an arsenical solution. This method and tests for controlling the strength of the solution are the results of Department research. About 31,000 dip-

[1] Chief, Bureau of Animal Industry, U. S. Department of Agriculture

ping vats are now in use, and during the last year the vat solutions required about 750 tons of white arsenic. The work has gone forward so successfully that since its beginning approximately half a million square miles of tick-infested territory have been freed from this pest. The undersized, unthrifty native cattle are either being replaced by better stock or are being bred up by the use of purebred sires of good type. Both the beef and dairy industries are now becoming important commercial activities in tick-free territory. It is a great work of reclamation—reclaiming the great empire of the South from a pest which sucked blood, spoiled hides, spread fever, and caused misery to stock and discouragement to man. The work of reclamation was based on applied chemistry; in fact, the dipping vats have appropriately been called canals to prosperity.

Through artificial refrigeration chemistry is also an essential part of creamery operation and meat packing in the South. When the climate denies natural ice, a refrigerating machine is a necessity, not merely a substitute, as it is farther north. Tanning of hides is likewise a chemical process, as is also the manufacture, from animal products, of the fertilizer that goes back to the farms to enrich the soil.

Thus chemistry has aided in eradicating a serious pest, in the better feeding of farm animals, in selling dairy products on a fair basis, in refrigeration, and in growing new crops for feeding man and beast. While I might enumerate many other instances, you will doubtless be more interested in current Department research work.

Meat Inspection Prevents Waste

Through the meat-inspection service the Bureau of Animal Industry supervises methods of preparing edible products from food animals in inspected establishments. All parts and products which are fit for food are marked "U. S. Inspected and Passed," and all unfit for food are destroyed for food purposes. The achievements of chemical engineering in the utilization of by-products are well known. There is almost literal truth in the assertion that the squeal is the only part of a hog that goes to waste. Yet the process of transforming the living animal into an inert mass of meat and products suitable for human food is beset with difficulties and dangers at every stage. The perishable nature of the material naturally makes necessary the utmost care and vigilance if losses due to spoiling are to be avoided.

While the duty of the meat-inspection service is to condemn and destroy all products which become unfit for food, and while this duty is performed without fear or favor, the inspection service is ever on the alert also to discover causes of spoilage and point out means of prevention. Accomplishments have been made in this field. Department workers have found the cause of rancidity and its prevention, the cause and prevention of ham souring, a means of reclaiming tank-water sour lard, and prevention of moldiness in oleosterin.

Rancidity of fats has caused heavy losses to establishments operating under inspection. Records show the condemnation of numerous large lots of lard and other fats on account of rancidity. In the early years of Federal meat inspection the causes of rancidity were not generally understood, but have been learned through the work of Bureau laboratories. Means for its prevention have been pointed out and an accurate chemical test made known by which rancidity can be detected before the fat has become unfit for food.

Tank-water souring of lard is another condition which has at times caused heavy losses. This condition develops in steam-rendered lard and is due to lack of proper care in drawing off the lard from the tanks so that a small amount of tank water is drawn off with the lard and remains suspended in it or settles to the bottom of the receiving tank. Tank water contains large amounts of soluble nitrogenous matter derived from the connective tissues of the fats rendered. It is naturally a splendid culture medium for putrefactive bacteria, and when tank water is present in the lard it is never long before evidence of the growth of such bacteria becomes manifest. Formerly all lard showing this condition was condemned by Bureau inspectors. Investigation of the subject by the meat-inspection laboratories disclosed that the decomposition, in the early stages at least, was confined to the entrained tank water and that the lard itself remained unaffected for a considerable time. A method of reclaiming lard, affected by this condition, by removal of the putrid tank water was developed and published in May, 1917. Since that time numerous lots of such lard have been successfully treated and saved for human food.

The development of mold in oleostearin has been another cause of loss to inspected establishments. Laboratory investigations have shown that the growth and development of mold in oleostearin is due to the presence of small amounts of water containing soluble nitrog-

enous matter, thus affording the molds the conditions necessary to their growth.

Ham souring is another cause of serious loss. In the curing of hams a certain proportion is found not to have cured properly but to have developed a condition commonly known as "sour" in the deep tissues next to the bone. This and other similar conditions grouped together under the head of "Souring" are responsible for the condemnation and destruction of millions of pounds of hams and other pork products. This problem has been attacked by the Bureau with interesting and valuable results. Ham souring is due to the development of a limited group of bacteria which evidently become disseminated throughout the carcass at the time the animal is slaughtered and are present in the ham at the end of the customary 48-hour period of chilling. Rapid and efficient handling of the carcasses through all stages of slaughter and dressing, rapid and efficient chilling together with low temperatures in the chill rooms, cutting rooms, and curing cellars, appear to be the reliable means of limiting losses due to this cause. The prevention of ham souring becomes then largely a problem of engineering.

The meat-packing industry is subject to substantial and annoying losses through depredations of rats, mice, roaches, and other vermin. Against these pests the service wages vigorous and unremitting war. In this connection a study of the effects of hydrocyanic-acid fumigation on foodstuffs was made to determine the possibility of using this agent in inspected establishments. It was demonstrated first by laboratory study on a small scale and later by experiments in commercial establishments that meats could be fumigated with this gas without danger, and the meat-inspection regulations have been modified to permit its use. Experiments and studies have also been made with the use of barium carbonate for poisoning rats, and sodium fluorid for eliminating cockroaches. Other studies of interest to chemists are the preparation of edible blood albumen and the dry rendering of fats.

Enormous amounts of blood are drawn daily from the animals slaughtered in meat-packing establishments. While blood has high food value, almost all of it is used for inedible purposes, principally fertilizer. One establishment, however, operating under Federal inspection is now preparing edible blood albumen. The operations of this establishment have received most careful and sympathetic attention.

The dry rendering of fats is another recent development of importance. Until recently, all large-scale rendering was carried out by the familiar steam-tank method. The edible fats are saved for human food but the residue is fit only for fertilizer. The processes of preparing tankage for fertilizer and the recovery and evaporation of the tank water are not only expensive but are responsible for the nuisances and offensive odors developed in and about the establishments. These processes are furthermore attended with heavy losses due to the escape of ammonia. These drawbacks and losses are avoided in the dry-rendering system, where the fats are rendered in a steam-jacketed rotary renderer by dry heat instead of in a closed tank with steam, and the residue put through a press or expeller. The dry-rendering system has the advantage of producing fats of better quality and of yielding a residue which is available for stock or poultry feed instead of fertilizer. The development and adoption of this system is being encouraged.

Vitamins in Meat

The food value, likewise, of meats has been studied from a biochemic standpoint. Since the absolute necessity for at least three vitamins in the human diet has been clearly established, it is desirable for us to know the vitamin content of our various foodstuffs so that an ample supply of these important substances in our diet can be assured.

Until recently meat (muscle tissue) was considered very deficient in vitamins A, B, and C, while the liver, heart, and kidney were known to be fairly rich in vitamins A and B. In view of the importance of meat as a foodstuff, it seemed desirable for the Bureau to investigate further the vitamin content of meat, as well as the various edible by-products of our meat food animals.

A study of the vitamin B (antineuritic) content of the edible tissues of the ox, sheep, and hog has been completed, with interesting results. The experiments were carried on with pigeons, several hundred birds being used. The liver, heart, and kidney of each of the three classes of animals were found to be rich in the antineuritic vitamin, while the other viscera had lower values. The most striking result of the experiment was that hog muscle was found to be rich in vitamin B, ranking with the liver, heart, and kidney. Sheep muscle has a considerably lower value, and ox muscle was relatively low in the vitamin.

Several other vitamin studies are in progress with the promise of interesting results.

Soft-Pork Investigations

Another noteworthy problem engaging the attention of the Bureau of Animal Industry is soft pork. Soft pork as compared with firm pork is considered an inferior product. Meat packers discriminate in price against "soft" hogs. The producer is paid a price which probably averages about two cents per pound less than that received for firm hogs. Carcasses of soft hogs are characterized by their failure to become firm after thorough chilling at from 32 to 38 degrees F., as do those of firm hogs. Feeds, such as peanuts, soybeans, certain rice by-products and mast, are without doubt the principal causes of soft pork, but there are other factors.

A great deal of chemical study is being carried out in connection with the investigation of this problem. Chemical tests are applied to samples of both back and leaf fat from each carcass. Melting point, iodin number, and refractive-index determinations have been made, in some cases all three being applied to a sample. When it is taken into account that approximately 2,000 hogs have been studied in this manner some conception will be obtained of the work involved. These results are used as a check on the physical gradings of the chilled carcasses, made by a committee of three. Contrary to expectations, the melting point has been found a rather unreliable measure of the firmness. The refractive-index and iodin number have proved more satisfactory.

Chemical Studies of Milk Products

In connection with its work on dairy products the Bureau has a great variety of projects involving chemical problems. In the manufacture of condensed and evaporated milk a study is being made of the physics and chemistry of the changes which take place when milk is coagulated by heat.

A new set of problems has been brought forward by the rapid development of the milk-powder industry. Our laboratories have been concerned chiefly with the causes of deterioration in milk powder and distinct progress has been made.

Ice cream is also a product which has brought new problems to the chemist. One of these is the defects caused by the crystalliza-

tion of lactose, which produces what is known as "sandiness." To explain and correct this trouble a study is being made of the crystallization of lactose under varying conditions.

One of the biggest problems, both from an economic and a chemical standpoint, is the question of utilizing dairy by-products. In this is involved not only the question of increased profit to the producer and manufacturer, but also the conservation of the food value of large quantities of skim milk, buttermilk, and whey now wasted or utilized inefficiently.

As one step in this direction a method has been developed of separating a soluble albumen from whey and the process of making casein and milk sugar modified to produce a whey of satisfactory quality for this purpose. A market has been found for this product and its manufacture is being put on a commercial basis.

Chemistry—Livestock—Human Welfare

In veterinary medicine, in the enforcement of quarantine laws in the disinfection of premises, pens, and stock cars, and in similar fields, chemistry plays a leading rôle. Frequently, work with livestock leads to valuable contributions to human medicine and welfare. This recently occurred when carbon tetrachlorid, found by the Bureau to be an excellent agent against internal parasites in dogs, proved effective also against hookworm in man.

I might discuss with you such problems as livestock poisoning by loco weeds and other deadly plants on which the Bureau is working, or chemical problems in the manufacture of biological products. But such work is rather technical for an occasion of this kind. My remarks are rather intended to convey to you an acknowledgment of the great service the science of chemistry has been to the country's livestock industry.

In its applied forms, chemistry has reduced losses and risks in production, has contributed to handling and marketing of livestock products, and has given needed information on their nutritive values so that consumers may select foods wisely. Perhaps chemists and stockmen are not as close personal friends as they should be, in view of the many interests they have in common. Stockmen, however, are a friendly sort, and chemists are by profession "good mixers." So I am sure that future relations will be even more cordial and mutually helpful than those of the past.

PLANT PRODUCTS—CHEMICAL RAW MATERIALS

By WM. A. TAYLOR[1]

Read at the Washington Meeting, December 7, 1923

With our food and clothing derived from plants, either directly or after conversion by animals or industrial chemists into forms more practical for human use, the fundamental importance of vegetation to chemical industry as a source of raw material is fairly obvious.

Leaving to others on the program those features likely to be more specifically related to the work of their bureaus, and restricting the discussion to a few of the more important plant resources that are not yet fully utilized, the following notes are jotted down as reminders of some fields perhaps not yet fully explored by the chemist. As will be observed, not many of these suggestions involve the production of crops specifically for utilization by the industrial chemist; in the main they consist rather of plant products unused or at best disposed of unprofitably which, if found practicable to use more efficiently, would tend toward constructive stabilization of agriculture and eventual benefit to producer and consumer as well as to the converter of the raw material into useful products.

Straw as Related to the Chemical Industry

The straw of the small grains, wheat, oats, barley, rye, and rice, and of buckwheat and flax, and the stalks of corn, offer a large field for experimentation along chemical lines. Enormous quantities of these various kinds of straw and corn stalks are produced annually in the United States. Corn is grown on more than 100 million acres, and the small grains and flax on more than 100 million more. These must average at least a ton of straw or stalks to the acre, producing, therefore, on this basis more than 200,000,000 tons of plant material, some portion of which potentially is available for use in manufacturing processes.

Straw and corn stalks are now principally for feed and as manure. In the main their use in this way is essential to the maintenance of productivity. In some parts of the country, however, (where

[1] Chief Bureau of Plant Industry, U. S. Department of Agriculture.

livestock is not kept in large numbers and where the use of manure is not profitable) they are burned. A large part of the total production is destroyed in this way. Recent experiments indicate that this material is worthy of attention by the chemist. It has been shown that gas for heat, light, and power can be made from straw by destructive distillation. Furfural also has been made from certain of these plant products. Further experimentation will doubtless reveal other products of importance, and make practical the manufacture of products now known.

A ton of straw contains about 16 to 20 pounds of potassium. Under certain circumstances, the ash left from burned straw might be collected and used as a source of potash.

The cost of handling and transporting these bulky products makes it impractical to ship them long distances. The paper factories which use some 150,000 tons of straw annually for making wrapping paper and straw board, manufactured products relatively low priced, consequently are located near the sources of supply. Higher priced products would permit the location of factories in grain-producing regions in which the straw is now destroyed.

Products From Corn

While corn is the most important source of starch in the United States and the bulk of all starch and allied products such as dextrin, glucose and glucose sugars are obtained from corn, together with corn oil, used extensively for culinary purposes and also in the manufacture of soap, paint, and rubber substitute, the rest of the corn plant is not utilized extensively in industry at present, though it has a large potential value. The stalks and cobs provide a source of cellulose which may be utilized in the manufacture of paper stock or in such products as celluloid, collodion, sizing and surfacing preparations, etc. Corn cobs may be used as a source of acetic and lactic acids, and also as a source of adhesives and furfural. The manufacture of the latter products has been developed by the Bureau of Chemistry of this Department.

Corn stalks can probably be so grown as to be utilizable as a source of cane sugar, should conditions necessitate it. Experiments by the Bureau of Plant Industry have shown that by removing the immature ears the sucrose content in sweet corn stalks may be increased to 10.44 per cent in comparison with 12.15 per cent in Louisiana sugar cane.

Sugar-Cane Bagasse

In the sugar factories with good extraction of juice from the cane, there is left from four to seven tons of bagasse per acre of a medium or good crop of cane grown. This bagasse is at present mostly used as fuel, displacing crude oil or coal which would otherwise have to be used. The bagasse is mostly fiber, but contains also a small amount of wax and various other constituents. Some attempts have been made at recovering the wax, and in the last few years progress has been made in preparing a kind of building board out of the fiber of the bagasse.

In the sirup-producing sections the extraction of the juice from the cane is usually much less nearly complete and the bagasse therefore contains too much moisture for fuel and it also contains a considerable percentage of sugar. From 50 per cent to 65 per cent of the weight of the cane out of a possible 85 per cent to 90 per cent is extracted as juice in the small mills in the sirup-producing sections. On the other hand, in the sugar-producing sections with the large mills only from 2 per cent to 10 per cent of the original juice is left in the bagasse. In the sirup sections the bagasse is largely wasted, or, at best, is used for litter in the corrals and thus put back on the field with the barnyard manure, or it is allowed to remain in a heap until sufficiently rotted to apply as a low grade of manure to the fields.

Sugar Cane Tops

The sugar cane tops comprise roughly about one-fourth of the weight of the cane grown in the fields and thus represents a yield of tops amounting to from three to five tons per acre. The common practice at present is to burn these tops after they have dried on the field. Where only small areas are planted in sugar cane and a relatively large amount of live stock, especially cattle, are at hand the cane tops afford some pasturage while they are fresh, or before the tips of the stalks have soured and the leaves have weathered badly.

Some work has been done by the Bureau of Plant Industry in the way of utilizing the tops for silage, and fairly good silage was produced. More elaborate experiments with silage, including also feeding experiments, have been carried out by the Bureau of Animal Industry at Jeanerette, Lousiana. An obstacle in the way of utilizing the tops for silage is the extra labor involved in collecting the

tops and preparing the silage during the cane harvesting time when all available hands and teams are urgently needed in harvesting and working up the crop of cane.

Long Fiber By-Products

Among the by-products resulting from fiber production, the bagasse or waste from henequen and sisal are most important in point of quantity. Many thousands of tons of bagasse are produced in cleaning henequen fiber in Yucatan and in Campeche every year, and there are also thousands of tons of bagasse produced in cleaning sisal in the Bahamas, East Africa, and Java. This bagasse contains small percentages of potash, phosphoric acid, nitrogen, and lime, but not enough of these elements to pay for its transportation for use as fertilizer, except to haul it out to the fields close at hand. It has been suggested for use as paper stock, but it is reported to contain elements making it difficult to clean so as to be used in a satisfactory manner for paper. It usually contains fifty to sixty per cent of its dry weight in cellulose. The bagasse of sisal has been found to contain a small percentage of lactic acid, but probably not enough to warrant its use as a source of this material.

Hemp hurds are produced in considerable quantity in the production of hemp fiber. These hurds have been demonstrated to be suitable for the production of a very good quality of paper stock, but at present they are found more valuable for use as fuel to furnish power and steam for the driers and in operating the hemp scutching mills where the hurds are produced. The same is practically true of flax shives produced as a by-product in the preparation of flax fiber.

Industrial Alcohol

The practicability of producing industrial alcohol upon a basis economically sound from crops such as potatoes and sugar beets, grown primarily for that purpose, will not be discussed here. As to the possibility of developing such an industry there can be no reasonable doubt. It would seem, however, that such development must await the arrival of materially changed economic conditions, especially with respect to the cost of competing products, particularly those derived from petroleum. When the economic need approaches, it will probably be necessary so to organize the production of the crops for this purpose that their growth will fit effectively into a specialized,

intensive type of farming. In this, livestock will need to play an important part, thereby utilizing the industrial residues effectively and making possible the maintenance of crop production through a well balanced intensive agriculture.

More Varied Utilization of Soybeans

The soybean, while grown in the United States in a small way for many years, is now rapidly attaining staple crop importance. It yields well throughout a wide climatic range and fits well into certain crop rotations where a summer legume is practicable.

The large increase in acreage of the soybean for seed production during the last three years has stimulated many manufacturers to take advantage of the industrial uses of the crop and its products, bean-oil and oil-cake. Factories in the United States are now producing from the soybean, oil, oil-meal, flour, soy sauce, special foods for infants and invalids. Investigations are now being made of the possibilities of milk powders and vegetable casein. In view of the rapidly increasing acreage and popularity of the soybean it is believed that it will become one of the leading farm crops throughout a wide geographic area.

The soybean differs quite markedly from most other plants in its greater content of nitrogen, oil and mineral substances, and in the character of these substances. Large quantities of soybean oil are used in the manufacture of lard and butter substitutes, rubber substitutes, soaps, edible oil, waterproof goods, enamels, varnish, paints, printing ink, celluloid, and lighting and lubricating oils. Quite recently, by a German process, lecithin is being extracted from soybean oil, which so far is understood to be the only known vegetable source of this substance. Undoubtedly many new trade uses can be found for soybean oil.

Soybean oil cake or meal is a most valuable product and has wide usefulness. It is highly concentrated and nutritious, and is valuable for all kinds of stock, and is now quite generally used for human food as flour and in various manufactured food products.

Tobacco for Nicotine Production

One subject on which the Bureau has been working has seemed considerably to interest manufacturing chemists, namely, tobacco as a raw material for the commercial extraction of nicotine. As is well

known, stems, leaf scrap, and other by-products of the leaf tobacco industry constitute the present source of supply of raw material. Effort is being made to devise practical methods for growing tobacco to be used merely as a source of nicotine. The nicotine content of tobacco stems (mid ribs of the leaves) and stalks is low and the methods of extraction are expensive. Again, tobacco, as such, has a relatively high value per acre. The problem, therefore, is to produce a sufficiently large yield per acre of tobacco of average nicotine content or to increase sufficiently the present content of nicotine in the normal yield to justify the growing of this crop merely as raw material for nicotine-extraction purposes. Our heaviest yielding commercial types of tobacco do not contain a sufficiently high percentage of nicotine while the types of *Nicotiana rustica* now available carry higher percentages of nicotine but produce relatively small yields of tobacco. We have accumulated much information regarding the relation of various environmental factors to nicotine production and have made progress in the major problem along the lines above indicated. Further work is needed, however, to secure the desired combination of high yield of raw material with high percentage content of nicotine.

Future of American Tannin Supply

The chestnut blight, a destructive fungus disease, is steadily destroying the chestnut growth of this country, and there is no prospect of stopping or of materially delaying its progress. Our leather tanning industry secures approximately one-half of its supply of native tanning material from the large chemical plants in the Southern Appalachians which extract the tannin from the chestnut wood. Our tanning industry is even now dependent to a considerable extent on foreign tannins and with the passing of the chestnut it will be even more so. It would seem fundamentally unsound for one of our large basic industries to be dependent upon tannins from other countries, chiefly tropical.

With a view to developing new domestic sources of tannin, the Bureau of Plant Industry is devoting considerable attention to the location and introduction of potential tannin-producing plants. In particular it is exploring the oriental chestnut areas in search of potential blight-resistant species of chestnut and closely related trees, and securing seeds and plant material of such as appear at all prom-

ising for introduction and testing in this country. Up to the present the most promising appears to be the Chinese sweet chestnut, *Castanea mollissima,* of which trees are now growing in a number of representative localities in the eastern United States and on the Pacific Coast. Recently some vigorous-growing species of Castanea and Castanopsis have been located in the upper Yangste Valley in China, of which it has been possible to introduce for testing small numbers of trees grown from considerable quantities of nuts collected and shipped to this country. It should not be overlooked, however, that the introduction on an extensive commercial scale of any trees new to America which would be capable of replacing our native chestnut would be a long-time and expensive undertaking, even if it should be found that one or more promising species measure up fully to the climatic, soil, disease-resistance, and other requirements. It would be entirely premature, therefore, to suggest that a satisfactory replacement of our chestnut as a source of tannin is in prospect, even with respect to the remote future, although this line of effort appears highly important and desirable to continue.

Miscellaneous Suggestions

As by-products of recent work of the Bureau of Plant Industry some features of more or less interest to chemists may be mentioned. One of these is the Chaulmoogra Oil industry in its relation to the treatment of leprosy. Other plants than the trees yielding the Chaulmoogra oil of commerce, notably *Oncoba echinata,* also have potential value in this connection. The ultimate economic development of industries from these plants and the proper utilization of the products therefrom are largely chemical questions which must be solved by chemical experts and chemical methods.

Tung oil is another potential possibility in the chemical field. The oil, as is well known, is obtained from the seed of the tree, *Aleurites fordii,* a native of China, but apparently adapted for culture in this country along the South Atlantic Coast and, particularly, in central Florida. The oil is used in the manufacture of high grade varnishes and paints; also in the manufacture of linoleum, and for many other purposes. It is our understanding that there are many chemical problems connected with the utilization of this oil yet to be solved.

The dasheen has potential possibilities as a source of special types or grades of starch. The starch of the dasheen is very fine

grained and might find a place in the sizing of textiles. There is a field here for future work along chemical lines. The tropical yams are also a source of possible starch production. As both the dasheens and yams are crops that give large tonnage on waste and poor lands in tropical countries, they may, at some future time, be found useful as a source of alcohol. These are matters, however, that must be determined by industrial chemical investigations.

Certain of the bamboos would seem to offer potential possibilities in the manufacture of paper. This would apply more especially to the small thicket-forming types of bamboos suitable for planting on wet and waste lands. Their probable utilization for this purpose would need to be determined largely by chemical studies conducted along industrial chemical investigative lines.

The avocado is making a place for itself as one of the important subtropical tree crops in this country. It is sold exclusively as a fresh fruit. Many efforts have been made to preserve the avocado but owing to rapid chemical and physical changes no work of this kind has been successful. Recently a representative of an important tropical fruit company came to us with a request for information which might be helpful in finding a way to preserve or can this useful product. Oxidation and blackening quickly take place when the avocado is cut. Here is an interesting problem for the chemist.

Oriental persimmons as a source of material for waterproofing are worthy of investigation. It has long been known that the Chinese and Japanese manufacture from certain of the oriental persimmons a product which they use in waterproofing paper. They also use this material for waterproofing their umbrellas, parasols, capes, etc. What the material is we do not know as, so far as we are aware, no chemical work has been conducted upon it. A problem of a chemical nature is involved in this matter.

It is not generally known that a very effective adhesive may be made from the mucilaginous or viscid endocarp of the berries of *Phoradendron, Ciscum* and related genera. A thin paste may be prepared by beating up the berries in water. The residue from the crushed fruit may then be strained off and the solution allowed to evaporate to the desired consistency. A low alcohol, phenol or some other preservative that will not cause coagulation, may be added. This preparation will keep indefinitely, and has been used by Dr. J. R. Weir in herbarium work, and in many cases was found to be more

effective than the ordinary library paste of the trade. It is possible that the preparation may be found of use in microscope and microtome technique. An adhesive may also be extracted from the berries of *Razoumofskya* species.

Many species of *Phoradendron* in the south and southwest produce berries in large quantities. In some sections *Razoumofskya* species are sufficiently abundant to admit of the collecting of berries in considerable quantities.

MARKETING OF FARM PRODUCTS

By HENRY C. TAYLOR

Read at the Washington Meeting, December 7, 1923

As chemistry has to do with the relations of the elements and combinations of the elements, so economics has to do with the relations of individuals and groups of people, particularly those relations which arise out of the effort to get a living.

In the Middle Ages and during the pioneer days in this country, these economic relations were few and relatively simple, but with the development of modern civilization, the grouping of people into occupations, the division of labor within the occupations, and the division of territory in the production of particular products, these human relations have grown complex and far reaching.

The problems involved in the marketing of agricultural products center about these human relations and I wish to emphasize, to-day, some of the problems that have arisen in the adjustment of these human relations, in which the chemist has played a valuable part in developing the means of making the adjustments.

The problems of marketing center about the question of securing a price for different grades of farm products corresponding to their respective values to consumers. In order that widely scattered producers may sell at fair prices it is necessary that they know the value of their products, not simply the value of wheat or corn or cotton in general, but the value of the particular grade of product which the given farmer has for sale. For this reason, the marketing work of the Bureau of Agricultural Economics centers about the market news service and the inspection service, both based upon standard grades for the various products.

Standard grades are essential to a news service if the farmers and merchants are to be kept informed, in more than a very general way, of the prices at which specific products are being sold in the distant markets. Standards are essential also as a basis for making long distance sales, or sales for delivery sometime in the future. It is particularly in connection with the establishment of standard grades and the development of technique essential to their application that

the chemists have made important contributions to the work of the Bureau of Agricultural Economics.

About forty years ago butter production in this country was beginning to make the transition from the farm to the factory. This was important not only from the standpoint of taking work out of the home, but also from the standpoint of producing a standardized product for the market, but when milk or cream was produced on a great number of farms and pooled for the purpose of making butter, it was difficult to know how much each farmer should be paid. If he was paid simply on the basis of the number of pounds of milk brought in, without regard to the quality of the milk, or upon the basis of the number of pounds of cream delivered without regard to the quality of the cream, there was a strong tendency to water the milk or partially skim it and the like tendency, in case cream was delivered, to keep the butterfat content low.

The chemists were called upon to solve this problem by providing a simple and reliable test for measuring the fat content of milk and cream. I need not go into the details, for you are all familiar with the various tests that were developed and the way in which the Babcock butterfat test, because of its simplicity and accuracy, displaced all others in this country. One cannot over-emphasize the importance of the Babcock test as a means of adjusting the economic relations of dairy farmers. The Babcock test made it practicable to pay the farmers on the basis of the amount of butterfat delivered.

As butter came to be manufactured largely in creameries by expert butter-makers, the man who could manufacture the greatest number of pounds of good butter out of a given amount of fat was sought after, but in due course of time the Government stepped in and set a minimum limit upon the amount of fat which butter must contain and a maximum limit upon the water content.

The chemists were instrumental, again, in providing moisture and fat tests for butter and in establishing this uniform basis of competition. For it is obvious that with a limit set, every buttermaker must manufacture butter containing practically the full water content. Otherwise he is not doing full justice to his patrons. The butter must not contain more than the water content permitted or he is doing an injustice to the consumer. The chemists and physicists have worked out this problem in a satisfactory way and the content of the butter has been standardized.

Another problem in the standardization of butter to suit the demands of consumers relates to the color and here, again, the chemists have created means for securing standard color. Thus it is that the chemist, dealing with the relations of the elements and their combinations, has contributed largely to the means of adjusting human relations in the butter industry and has made possible the factory method of manufacturing butter. The Babcock test has aided also in adjusting equitably the basis of sale of fluid milk in channels of trade. These are only a few of the many ways the chemist has aided the dairy industry, for in the processes of dehydrating milk, and in other processes, the chemist has rendered necessary services.

Recently a similar contribution has been made in the marketing of cantaloupes. Cantaloupes produced in the Imperial Valley are sold all over the United States. It is desirable that these cantaloupes be sold on a shipping point certification, which is now being provided by the Federal and state governments, but, in order that the character of the product may be specified accurately, it is necessary to know the sugar content of the cantaloupes. By the aid of the chemists a simple device was soon developed whereby the juice of a few typical melons is tested by a hydrometer, so graduated as to give a direct reading of the sugar content. Knowing the sugar content, as well as the other characteristics of the melons, it was possible to sell them in distant markets on the basis of the Federal certificate.

In the standardization and the classing and grading of cotton, no chemical methods are used so far as I know, but in establishing the grades, account had to be taken of the fact that certain yellow tinges and stains could be bleached out, whereas the blue tinges and stains could not be bleached out, in the manufacturing processes. The resulting system of cotton standards takes these facts into account and segregates "yellows" from "blues."

The standards for shelled corn provide that each numerical grade shall not contain more than a certain percentage of damaged kernels. The question naturally arises, "What constitutes damaged kernels?" After it is harvested and is moving through the various stages in commerce, corn deteriorates under certain adverse conditions in storage and transportation. This deterioration is marked by decomposition of the germ in the kernel. Acid-reacting substances are developed much in excess of the normal. If the determination of the amount of damage had to be made merely by looking at the corn and

making an estimate, the results would not be very dependable, but at this point the chemists came to the rescue and showed how to extract these acid-reacting substances with alcohol and how to determine the degree of acidity by titration with alkali solutions of known strength. This method has added greatly to the efficiency of the inspectors in applying the Federal standards in the grading of corn.

In the marketing of wheat the problem is to find some means of designating wheat of different qualities in such a manner as will make possible a reflection of the milling value of the wheat in the price paid to the farmer. The Federal wheat grades have been established with this in view. Wheat is divided into classes on the basis of its botanic varieties, into subclasses on the basis of the hardness of the kernels and into grades on the basis of test weight, moisture content, damaged kernels, foreign material other than dockage and wheat of other classes. In order to make application of the standard grades, certain physical and chemical equipment has been developed. The method used in determining the moisture is based upon the principle of distillation, whereby the water in a known quantity of wheat is distilled off and collected in a suitable measuring device, which makes it possible to read the amount of moisture present in terms of percentage. The man who applies the test does not need to be a chemist, for the chemist has worked out the method and laid down the rules to be followed by the inspector. In making the other grade determinations, physical rather than chemical devices have been developed.

In recent months important progress has been made in devising means of separating foreign materials from wheat which, it is hoped, will eliminate certain difficulties which have confronted the millers in times past because of the presence of cockle, wild peas and other similar materials, not removable by ordinary methods.

The biggest problem that confronts us at the present time arises from the fact that the gluten in wheat, which is the most important factor in determining its value, is not readily determined by the inspector. We have records showing a difference of as much as 20 cents per bushel in the price of different lots of wheat of a given subclass and grade due to difference in the quantity and quality of the gluten content. The Federal grain standards recognize differences in the quantity and quality of gluten only in so far as these differences are covered by the statement of percentage of dark hard

and vitreous kernels. While this is a valuable basis for discriminating between wheats of different subclasses of a given class, yet it does not give a sufficiently close basis for valuing wheat, as is indicated by this wide range in price of wheat of the same subclass and grade. It is well known that the large mills and some of the state inspection laboratories have developed means of making quantitative tests of the gluten content of wheat but these tests have not yet been simplified to the point where they can be used as a regular method in the inspection service.

We have, therefore, a challenge to put up to you, the chemists of this country. A Babcock test for the gluten content of wheat is wanted, one which will be simple enough to be used in every grain inspection laboratory in the country and, at the same time, one which will give a single reading that covers both the quantity and the quality of the gluten in a given amount of wheat. In other words we want a test which will show the baking value of the wheat. This I have no doubt you can give us, and as soon as the device is perfected it will be made use of in the administration of the Federal grain standards. Many other chemical tests are used in the administration of these standards: the sulphur test, the measurement of the degree of stain on oats and barley, the test for the oil content in flax, etc.

These are a few examples of the important way in which methods developed by chemists are used in adjusting the relations of men in the transactions involved in the marketing of the farm products of the country. We are using your methods every day and we want you to develop more and better methods for our use.

FIXED NITROGEN RESEARCH LABORATORY

By DR. F. G. COTTRELL

Read at the Washington Meeting, December 7, 1923

It is a misnomer to term this a paper. I want to extend to those of you here, who were not able to get to the laboratory this afternoon, a cordial invitation to visit us before you leave tomorrow. At this time of year the Government work is on an all-day schedule, even Saturday. Our laboratory starts at 8:30 A.M. and though it nominally closes at 4:00 P.M. we shall be glad to extend that time if you are there and have not gotten over all the ground. We had quite a delegation there today, and with apologies to them for what I may repeat tonight of what I said to them at the plant about the laboratory, perhaps a word or two would be of use to those of you who were not there as indicating what you may expect to see and to give you an idea whether there is anything there of sufficient interest to you to justify your making the effort.

The Nitrogen Laboratory was established in March, 1919, about the time that the large scale operations of the Government at Muscle Shoals and Sheffield were being shut down, with the idea that it would continue and intensify the research work which had been carried on in connection with these plants, now that the larger scale production and tests were being discontinued on account of the costs. That establishment of the laboratory was under the Nitrate Division of the Ordnance Bureau of the Army. The sum of $300,000 was made available for the first year, and our expenses have been between $200,000 and $300,000 each year since. We have at present on the staff about 75 employees of whom about 35 are chemists, physicists, and engineers. The Laboratory continued under the War Department for a little over two years, and in July, 1921, was transferred to the Department of Agriculture, emphasizing the transition of the major interest from munitions to fertilizer applications.

At the outset the Laboratory's largest and most immediate responsibility was to be in readiness to assist and advise in starting up the existing plants, particularly the one that was ready and is still ready to operate at any time when the money is provided. That is

the No. 2 or cyanamid plant. So, a large part of our energy was devoted to that problem for a year or more. The laboratory was first under the directorship of Dr. A. B. Lamb of Harvard, and later on Dr. R. C. Tolman, now of the California Institute of Technology in Pasadena. From the start, however, attention was given not only to the cyanamid process and its application in peace times, and the re-adaptation of the production to peacetime work, but also to study the synthetic ammonia process which was the basis of Plant No. 1 at Sheffield, where a modified Haber system was installed during the war. The electric arc and other processes were also included in the general program but to a lesser extent.

The point of most intensive attack in the research field was the improvement of the ammonia catalyst and the determination of the best conditions for preparing and maintaining a serviceable catalyst. The catalyst which we attempted to apply during the war was of an entirely different type from that now used, or that was used in the German plants during the war. The original plan at plant No. 1 was to use a sodium amide catalyst while today practice the world over seems to have settled down to the use of a catalyst with metallic iron as its base, carrying usually, however, small amounts of other elements, called promoters, which essentially modify the properties of iron, particularly in making it more active at lower temperatures, and also less subject to deterioration, especially from over-heating.

The real chance for reducing costs on ammonia fixation lies in the cheapening of production of hydrogen, but before we could approach the problem definitely in that direction we had to attack the heart of the problem and be sure we had a good and available catalyst. The catalyst was rather the obscurest part of the problem as we approached it at that time, and so, at the start, the problem centered very definitely around that phase of the question. We feel now that the work has progressed to a point where we have the catalyst sufficiently defined and under control so we can pass on and begin to place more emphasis on the methods for hydrogen production, which we are now studying more intensively. That will be one of our chief problems this year and probably for a good while to come, as it is a subject with enormous possibilities.

There is also the question of plant design, including the extension of the process at Sheffield and elsewhere to higher pressures. The development of the work in later years has been more and more

toward high pressure operation, Claude having gone as high as 1,000 atmospheres in his plant while Casale, Fauser and others have designed the normal operation of their plants from 250 to 600 atmospheres, although I understand that in plants in Japan and Spain the former have recently increased their yields by running the pressures up to 900 atmospheres. In other words, when one builds a system for such pressures,—with the present knowledge of materials of construction the factor of safety employed is usually large enough so that when the plant is put into operation, if your nerve holds out, you generally push it up at least experimentally to get the maximum product out of it until it reaches the pressures that some other fellow set out for at the start. So I think we can hardly classify systems too rigidly on the question of pressure, but must expect to find this characteristic shading off somewhat from one plant into another, under the operating conditions. We have rather come to look upon pressures of 250 to 350 atmospheres as perhaps the most expedient to aim at in the immediate future, in this country, these pressures for practical purposes being chiefly determined by the upper limit for which standard machinery for compression has as yet been developed and come upon the market in this country.

The compressor people have worked out their methods pretty thoroughly, and are ready to supply standard machinery under sufficient guarantees to make it practicable to go to these pressures and, will later undoubtedly go to higher pressures. The development of the nitrogen fixation industry will probably be a very potent factor in hastening this development.

On the other hand the lower limit is established by the question of smaller yields which brings with it that of thermal equilibrium in the circuit, since at lower pressures, especially in small units, you may have to supply considerable auxiliary heat usually in the form of electric energy in your bomb, and it calls for a somewhat more extensive heat exchanger system for gases coming and going. But when you get up to say 300 atmospheres pressure the reaction goes further, you catalyze a larger per cent of your gases, so that more heat is developed and you can get a selfmaintained temperature from the reaction itself without changing the capacity of your heater. These are among the governing factors in our minds at present for the design of plants.

We consider that plants down to one ton of daily production of

ammonia are quite practicable, where by-product hydrogen is available and the plant is thus to be established as a by-product operation in another industry. There is one Casale plant going in at Niagara now for about 8 tons daily production, using by-product hydrogen from the Hooker Electro-chemical Works, and others are expected to follow.

If you come to the laboratory tomorrow you will see a plant of about one-fourth ton daily capacity operating on electrolytic hydrogen as an experimental unit. We are gradually raising the pressures, starting from 150 and planning to go up in this event to perhaps 350 atmospheres.

One of the difficulties in the design of catalyst bombs is to get steel that will resist the action of hydrogen, nitrogen, and ammonia at the working temperatures and pressures. The nitrogen or the ammonia tends to form nitrides, although it may be only in a transitory way, and the hydrogen tends to remove the carbon of the steel as methane so that ordinary steel tends to go to pieces rapidly by contact with the gases. To determine a way by which to protect from chemical action the parts that have to stand the mechanical strain and thus separate the chemical from the purely mechanical problems, is part of the work that we have planned for this year.

You will see there at the laboratory the gradual development of the catalyzer testing, which was a large part of the early work at the laboratory. A large number of the catalyzers were first tested on a small scale in little bombs, which did not in themselves represent complete ammonia systems. We simply catalyzed the gases and analyzed the resulting gas without attempting to remove the ammonia as done in the working plant. Series of tests were conducted on the various catalysts at 1 atmosphere, 30 atmospheres and at 100 atmospheres, which latter was then our standard working pressure, and in a large number of cases we made other tests, as for instance, in a larger plant over a longer period, sometimes five or six months at a time, to see how well the catalysers stood up under steady circulation, and also how they behaved when impurities were purposely added to the gas.

Chief among the impurities which interested us were moisture carbon monoxide, sulphur and so on. The whole behavior of the catalyst has to be defined, not in terms of one variable, but in terms of all the variables with which you have to deal, including temperature, pressure, impurities, and speed of flow of the gas.

So that there may be no such things as "the best catalyst" for all conditions, even tho there be for a definite set of conditions. I like to compare this work on catalysts with a study of an alloy steel. It is a case of fitting a special product to meet special conditions. Those of you who have read the earlier papers from the laboratory and remember the graphs given there for the performance of different catalyzers at different temperatures, may recall how the curves intersected, and that the best catalyzer at one pressure might not be the best one at another pressure. In other words, the order of effectiveness was not the same. The arrangement of a series of catalyzers would be quite different at different pressures.

So much, perhaps, for the ammonia work, except to indicate that at the laboratory you will see the various steps of this process, and the engineering features they embody, pretty well illustrated. We are cooperating now with several of the manufacturers who are getting into the work which I have outlined, and our purpose is to be as helpful as possible to all those who wish to enter the field. The original establishment of the laboratory had as an incentive the Government's ownership of these large plants, but that was merely a starting point. No matter what becomes of the large plants the laboratory must function so as to carry forward and help the industry, and to help particularly the smaller and the newer user of of these processes who may try legitimately to get into that industry. The larger group will naturally develop its own work more and more, but it is important that the industry be spread fairly broadly. During the wartime we were impressed with the very great lack of trained men to step into these industries. Nitrogen fixation in one of its important aspects is distinctly a wartime industry, and the more people we have trained in that work in practical ways and working it out from different angles, the more stability we have in the country as a war reserve, so that we look upon the encouragement of nitrogen development in plants irrespective of the size, as an extremely important measure, and one on which I hope that the laboratory will continue indefinitely. We are making our information as freely available to everyone who wants it as we possibly can.

With regard to the other processes that you will see at the laboratory, the cyanamid work has already largely covered most of what was first planned in a survey of the practicable peace time uses of Plant No. 2, but we are still going on with some aspects of the work.

For example, the use of cyanamid directly as a fertilizer would be very important if it could be applied more generally. Taking power at two mills a kilowatt, which is perhaps a reasonable value for certain large blocks of power, we could probably fix nitrogen at 9 cents a pound in the form of cyanamid at Plant No. 2, with reasonable charges for amortization and maintenance. If, however, you have to change it into ammonium sulphate, it would add about 5 cents more. And that makes a wide enough spread to make it a very important matter to get an outlet for the cyanamid direct.

Cyanamid does not lend itself readily to mixture with the standard fertilizers used today, and it is generally assumed that about 60 pounds of cyanamid to a ton of mixed fertilizers is about as much as it is safe to carry by and large. Cyanamid, however, can be mixed quite readily with certain other types of phosphate materials such as the basic slag, and calcined phosphate, and if those materials can be used widely, it might open an outlet. The laboratory has been making some studies along this line in cooperation with the Bureau of Plant Industry.

The production of urea from ammonia or cyanamid is an interesting problem on which the Germans have done quite a little and which may increase in importance at any time in this country. We are working on this also.

The possibility of decreasing the cost of cyanamid production seems very much less hopeful than in the case of the direct ammonia synthesis. The process is more efficient compared with its limiting possibilities than these other processes. There is less apparent chance for improvement in the costs. So that in a general sense we can look upon the cyanamid process as becoming probably more and more rapidly obsolete. It certainly is, in regard to new plants. As to operating those already constructed, where you can largely write off the capital charges it is a thing which has to be considered.

You will see quite a little work going in a general investigation of possible other processes. We have tried to keep abreast of the investigations in some of the processes that have not been as successful or popular as yet, and thus not overlooking any opportunities such as the aluminum nitride reactions or the cyanide processes. We are finishing up some of the more fundamental work on these reactions—fundamental data that should be of interest to chemists working in this field. Some of this material may very likely have

been collected elsewhere in commercial laboratories, but in any event is not generally available so we hope to publish it soon. In general we are doing considerable work on the collection of fundamental data for nitrogen fixation, no matter in what field it falls. We were interested to find out about the relationship of the gases coming from the ammonia catalyzing chamber. Recently for example we were studying the removal of ammonia from the catalyst exit gases by refrigerator but we found that we were not getting as much ammonia out of the gas as extrapolations from the tables available seemed to indicate that we should. We at first suspected that it might be due to lack of sufficient heat interchanger surface, or that we were getting a mist formed that would go through without depositing, and we discussed the redesign of the apparatus from these standpoints. Finally however we made direct determinations of vapor pressures and partial pressures of ammonia in the high pressure nitrogen-hydrogen mixtures we were using and found that the divergence from the gas law relationships ran up to 20 per cent or more. It was not long after that, in discussing the work with one of the commercial firms that we found they had had exactly the same experience as we and were considering at that time shutting down a plant and actually redesigning a part of it to overcome the supposed difficulties. We gave them our data, and it saved them from an unnecessary and useless shutdown and reconstruction of the plant and set them on the right trail.

At the time the laboratory was founded the Government had no arc process plant, so that our work in that field has not been so extensive. But we felt that something should be done for the maintenance of complete information even there and that has developed into some rather interesting lines.

We have particularly tried to segregate the phenomena going on in the arc, particularly to discriminate if possible between the purely thermal reactions and any specifically electro chemical or photo chemical elements of the process. You will thus have a chance at the laboratory to see the work in connection with "active" nitrogen that we are doing there. If you pass a high frequency discharge through a stream of nitrogen at a pressure of a couple of centimeters of mercury we will say and have the stream flowing on at a fairly rapid rate, you will have for the good part of a second a very vivid glowing gas which is extremely reactive, and will under

this disturbed condition, combine with substances as inert as mercury vapor to form nitrides and yet will not react with hydrogen. We do not as yet actually know what active nitrogen is. Those of you who heard Dr. Foote's discussion of the field of spectroscopy and the new fields of chemistry which have been opened up, will understand how we are trying to work into the phenomena and get at the solution.

Another interesting aspect of the work is what is being done in the bacterial field. That started out not as a broadly chemical bacteria investigation, but as an adjunct to the work on cyanamid. We were investigating the various compounds of cyanamid, as to their application to fertilizers, and the limits to which they could be carried, and one of the important things to be determined was the effect of cyanamid and its derivatives on the bacterial flora of the soil. One of the limiting properties of cyanamid was its toxic effect, and the toxic effect of some of these derivatives on the bacteria of the soil. Dr. Allison who is in charge of this work came to us first to handle that part of the subject, but his field has greatly broadened and at present he is chiefly interested to find out how certain bacteria manage to fix atmospheric nitrogen at ordinary temperatures. We have been trying to get at the bacteria's chemical secrets with the idea that if we could find them out we could use them perhaps to better advantage, than even the bacteria themselves. It may not be as complicated an organic reaction as it at first appears, but I do not want to go into any great detail on that at present.

You will see also our electric furnace equipment for handling various phases of this work. The laboratories and shops are spread out over quite a number of buildings there, and we shall be in attendance all day and very glad to see any of you who are able to come out.

Dr. Patrick was too modest in the presentation of his own paper and so I must speak of his work on silica gel, and the broad possibilities it may have in our work. We have been trying out some work in this line and it looks very promising. It is an attractive field and it may be an entering wedge in reviving some of the older processes that we have looked on as passing, such as the arc process. Whether the primary reactions are accomplished with the arc or thru combustion processes (like the Häusser process) or otherwise, the question of the subsequent treatment of the gases is a serious one

and one in which we think the use of an absorbent like silica gel may prove very useful. If we analyze the arc process, there are three chief drawbacks—the first all-controlling factor is the large power consumption. That has stood out beyond the others. Whether that can be materially reduced either by further and more fundamental studies of the electrical discharge in gases or thru combustion processes remains to be seen, but the question is certainly still an open one. The second drawback is the size and expense both in first cost and operation of the present absorption systems. That has not only been a burden to the process as the latter stands, but it has prevented us from considering any modifications of the oxide formation which would lead us to more dilute oxides of nitrogen even if there was any possible cheapening of the oxides by so doing. So that if we could get a more compact and cheaper method of absorbing the gases, using a different absorbent than water, you might not only reduce the cost at this point but also open a wider field for experimentation and development in the actual oxidation itself.

And, lastly, for peacetime development you don't want nitric acid. It is at present expensive to put nitric acid into a satisfactory fertilizer product which the American farmer is ready to accept. There is a field here on which a great deal can be done and in which the Bureau of Soils is doing some most important work. So that on these three points with respect to the fertilizer constituents, you have excellent opportunities for improvement which may bring back, one of these days, direct nitric acid processes. The first of these points to yield will perhaps be other absorbents, and the new absorbents which Professor Patrick has brought us are directly in that line. I extend a cordial invitation to all of you who have not been out there today, to visit our laboratory [applause].

Discussion

President Howard: Before this meeting breaks up there is one thing that has been borne in on my mind by these talks on atmospheric nitrogen. It seems to me that this extremely important development is in a very critical state in this country at the present time. It is in great danger of getting into the hands of Government operation, and the interesting thing that Director Cottrell has brought out, the most interesting thing to my mind, is the widespread interest that there seems to be among manufacturers in various lines in get-

ing into the fixation business and starting it up. They will not go into it unless they feel they are entering a profitable field in which they can make money by development. If they have got to compete with the Government, which may make up deficits by appropriations, it will immediately stop all development. You have the object lesson of the operation of ships at the present time. The Government is in the shipping business and the Leviathan is being operated, I understand, at enormous loss today in competition with other ships, and the legitimate ship operators are throwing up their hands and don't know what to do. They can do nothing when they are operating against the United States Government, which considers no cost, but calls on Congress to make up deficits. It seems to me that this industry of fixation today in this country might be compared with the automobile industry of about 1900. In 1900 the automobile industry was highly developed in France, excellent machines were made there, and it was well developed in Germany also. Supposing at that time in the interest of farmers or some particular class, that the Government has decided that it ought to go into the manufacture of automobiles in order to reduce the cost, and to give farmers help. Can you imagine that today we would have had cars the equal of Ford cars and at the low cost of Ford cars, under Government manufacture? That shows what independence, initiative and competition unhampered by the Government has brought about in a new industry.

If this new field gets into the hands of the Government I can imagine nothing that would stop its development so quickly, and I don't know of any organization better than this one to bring out that point. I am merely offering that as a suggestion tonight. The matter has come up or is coming up in Congress regarding Muscle Shoals, and of course the Government is interested in selling that plant. I do think that the importance of emphasizing that under no condition should the Government go into commercial production of fixation of nitrogen, is important. And if you feel that there is anything in it (it is of course too late to appoint a committee to draw up resolutions) a motion could be made giving the Council power to draw a resolution along these lines, emphasizing the point that a widespread and growing interest is developing among manufacturers, and it is only a question of time, in our belief, when nitrogen fixation will develop into a very widespread and great industry in this country, provided it is left alone, and given a fair chance to develop under competitive conditions.

PROFESSOR SMITH: I move that the Council be authorized to keep this matter in mind and be empowered to use their own discretion as to what they will do about it.

[The motion is seconded.]

DR. H. A. CURTIS: I heartily approve of the position you have taken on Government operation. I think the motion will do no harm, but on the other hand will have little effect, because I think there is no idea that the Government will go into commercial nitrogen fixation. However, I want to point out that in my opinion, with such a motion as this, there is still a Government program in nitrogen fixation which ought to be encouraged, such work as the laboratory is doing. I think the feeling that many people have that the whole of this nitrogen question will be settled, that giving Muscle Shoals plant to Henry Ford will give us fertilizer at one-half the cost, and other similar ideas, are absurd. Nothing could be more untrue. The only way we will get low fertilizer is by the entering into this nitrogen fixation game of a number of private interests. The Government has a part in this development, by encouraging the industry through supplying of such data as Dr. Cottrell and his co-workers are gathering at the laboratory. And while we thoroughly disapprove of Government operation of anything that private enterprise can operate, still I think it might well be pointed out that the Government has a function which it can perform.

PRESIDENT HOWARD: I am in favor of that proposition, and I do not criticize the work that Dr. Cottrell and the Government are doing. It is a splendid work, helpful to the industry in every way. But I was pointing out the other side of the question. While the Government might not go into Government operation, yet if it puts millions of dollars into plants and then sells them at a mere fraction of the cost, to certain interests, it certainly has subsidized those interests and may, for the time being at least, interfere with the legitimate development by people who would have to pay out real money for the development of new enterprises. That is something which should be borne in mind, in the way in which these huge waterpowers are disposed of.

Is there further discussion?

PROFESSOR SMITH: This motion had to do with the encouragement of private initiative, and the suppression of Government competition, and not with the Government development work at all.

PRESIDENT HOWARD: Absolutely not.

PROFESSOR SMITH: And that Government development work should be along the line of helping private initiative.

PRESIDENT HOWARD: Exactly.

MR. MOREY: I think the Institute ought to enter into any political question with the greatest caution. There is a time and a place for all things. When we come to a matter of political questions at the last minute of the last hour of the last session, it is late to take up a question of this sort, and it ought not to be run through quickly.

PRESIDENT HOWARD: This is not an attempt to run anything through, but a motion to leave the matter to the discretion of the Council. The Council has been elected by members, and is supposed to be composed of men representing the members and therefore ought to have the confidence of members. This matter has come up tonight, but it would have been brought up earlier if the subject had been discussed earlier. I suggested the matter at this time because there would be no other session of the Institute as a whole, before Congress might act on some of these matters. Are you ready for the question?

[Cries of "Question."]

[Upon a viva voce vote, there were responses of both aye and no. A rising vote being called for, upon a division it was found that 12 members had voted in favor and 2 members opposed, so the adoption of the resolution.]

PRESIDENT HOWARD: It is a vote. Are there any questions or remarks with further reference to Dr. Cottrell's paper? [No response.] If not, I will declare the last session of the meeting closed.

THE RATE OF OXIDATION OF NITRIC OXIDE

By W. A. PATRICK and M. LATSHAW

Read at the Washington Meeting, December 7, 1923

The oxidation of nitric oxide by oxygen is a reaction that has been greatly studied by chemists, because of the important bearing the kinetics of this reaction has upon the problems relating to the recovery of the oxides of nitrogen. Recently a careful investigation of this reaction has been finished by Bodenstein, and his results are so remarkable that it was thought worth while to repeat his experiments. In brief, Bodenstein found that the reaction proceeded strictly according to the equation

$$2NO + O_2 = 2NO_2 \rightleftharpoons N_2O_4$$

i.e. the velocity of the reaction was proportional to the product $(NO)^2$ (O_2). Furthermore it was found that the reaction was faster at low than at high temperatures. These results are noteworthy because, if substantiated, they indicate the first real example of a gaseous reaction occuring entirely in the gas phase that proceeds with a negative temperature coefficient of velocity. Such a reaction presents certain difficulties of interpretation that up to the present have not been satisfactorily explained. Bodenstein himself believes that the negative temperature coefficient is a result of the fact that three molecules must collide in order to form the reaction product. Others hold that such an explanation is inadequate, and advance the idea of the reaction proceeding by means of intermediate oxides. A number of such oxides have been assumed and various experimental proofs of their existence have been brought forward from time to time. Bodenstein dismisses all such efforts and points with insistence to his quantitative measurements which, according to him, admit of interpretation only on the basis of the simple reaction.

It is well known that this reaction is catalyzed by a number of substances, notably charcoal and silica gel. In the case of the latter substance, which is in no sense a general oxidation catalyst, it is difficult to imagine the mechanism of the catalytic operation. Of

course, it is difficult if not impossible to state correctly the mechanism of any catalytic change, but in the present case it appears that all the catalyst could do would be to remove the products of the reaction. Such an effect would not change the partial pressure of either the NO or the O_2, and as Bodenstein contends that the reaction occurs entirely in the gaseous phase, it follows that the removal of the products of the reaction should not effect the speed of the reaction. If the reaction did take place on the walls of the vessel then the explanation of the peculiar facts relating to the speed of oxidation would be greatly simplified.

If we follow the thought that this reaction takes place on the walls of the containing vessel, at any rate at low temperatures, we shall be led to the following mechanism: Nitrogen tetroxide having the highest critical temperature of the four gases NO, O_2, NO_2, N_2O_4, would be the first to condense on the surface of the containing vessel. This film of N_2O_4 would increase with increasing concentration of tetroxide and also with decreasing temperature. This last factor would operate in two ways in bringing about the condensation of the tetroxide—first by shifting the equilibrium $N_2O_4 \rightleftharpoons 2NO_2$ toward the left, and secondly by increasing the absorption of N_2O_4 per se. It would therefore follow that a decrease of temperature would favor the coating of the reaction chamber walls with a layer of condensed N_2O_4. Assuming that the oxidation of the NO occurred in the absorbed layer of N_2O_4, it would follow that the course of the reaction should be autocatalytic, i.e., the velocity should be slow in the beginning, rise to a maximum, and then decrease. Bodenstein however did not observe any such behavior, but as will appear from our experiments, his method of study was not sufficiently refined to bring out such effects at the beginning of the reaction.

If we postulate that NO will be taken up by N_2O_4 to form N_3O_2, which in turn could be oxidized back by O_2, to N_2O_4, then we might imagine the walls of the vessel as serving as an anchor for the N_2O_4, thus acting as an anvil upon which the NO and O_2 molecules could strike, each impact forming more molecules of N_2O_4. The reaction would then become

$$N_2O_4 + 2NO = 2N_2O_3$$
$$2N_2O_3 + O_2 = 2N_2O_4$$

from the above it can be seen that the rate of the reaction would still depend upon the product $(NO)^2(O_2)$. Such a mechanism would easily explain the negative temperature coefficient of the velocity, and furthermore would account for the catalysis by the chemically inert silica gel.

It was purposed to study the kinetics of the above reaction from the standpoint of the above ideas. The method employed by Bodenstein was adopted, which consists in bringing known volumes of NO and O_2 into a reacting chamber and noting the decrease in pressure on a manometer filled with bromnapthlene. No attempts will be made to go into the details of the apparatus in this paper, but a complete description of both the apparatus and the details of manipulation will be published later. It will be perhaps sufficient to say at this time that the reaction was followed by photographing the bromnapthlene manometer at intervals of 15 seconds. Furthermore two reaction chambers were used, which differed in the ratio of surface to volume. It being thought, that in case our postulates regarding the course of the reaction were true, that the velocity should be greatest in the reaction chamber showing the largest surface.

Calculation of the Results

The decrease of pressure read on the manometer at any time does not directly measure the amount of NO or O_2 that has been converted into the higher oxides. This is due to the fact that the NO_2 is immediately partially polymerized to N_2O_4, and the extent of the latter change is dependent upon the partial pressure of the N_2O_4, $2NO_2$ system. At the beginning of the oxidation when there is little of the higher oxides present, the latter must be practically all in the form of NO_2, as the reaction proceeds the dissociation of the N_2O_4 grows less and less due to the increase of pressure. It is possible to take these changes into account and to correctly calculate the extent of the reaction at any time from the measured decrease in pressure. If Δp represents the decrease in pressure in mm. of bromnapthlene at any time, then

$$\Delta p = -2X - X + X(1 + \alpha),$$

where $X =$ decrease of pressure due to the disappearance of oxygen and $\alpha =$ degree of dissociation of N_2O_4.

In other words, if the degree of dissociation of the tetroxide were known at each Δp then the amount of oxygen that had reacted would be equal to

$$X = \Delta p/(\alpha - 2)$$

and the amount of NO measured in mm. of bromnapthlene would obviously equal to $2X$.

The evaluation of α at each Δp was done as follows: In the dissociation of the tetroxide it can be shown that the dissociation constant K is related to α in the following manner:

$$\alpha^2 = \frac{K}{4p + K}.$$

By means of this equation it is possible to calculate α corresponding to various pressures. It has been shown that Δp is proportional to $(\alpha - 2)$ and the pressure of the higher oxides is proportional to $(1 + \alpha)$, therefore it follows that

$$\Delta p = P\frac{\alpha - 2}{1 + \alpha},$$

which relation allows one to draw a curve expressing the variation of α with Δp. By means of such a chart the value of α could be read off corresponding to each measured Δp.

In as much as the oxygen was always in excess, the speed of the reaction was referred to the concentration of the NO. Accordingly a curve was plotted showing the decrease in the pressure of the NO at each interval of time. The initial pressure of the NO and O_2 were calculated from the measured volume of the two gases that were introduced into the reaction chamber. The speed of the reaction was determined by evaluating the tangent to the above curve. Experiments were carried out at four different temperatures, and at each temperature the two different reaction chambers were used. The following is an illustration of the results of a typical experiment:

From the above it is to be noted that at the end of 15 seconds the pressure of the NO is only 206.4 mm., corresponding to a decrease of 214.4 mm. In other words, 51 per cent of the initial amount of the NO has been oxidized in 15 seconds. At the end of 2 minutes only 9.7 per cent of the original NO remained unconverted.

EXPERIMENT No. 15

Small surface. Temperature 0°. Initial O_2 pressure 433.5, initial NO pressure 420.8.

Time (sec.)	Δp.	α	x	(O_2)	(NO)
15	170.1	.413	107.2	326.3	206.4
20	206.3	.388	128.0	305.5	164.8
25	227.9	.374	140.1	293.4	140.6
30	244.3	.365	149.5	284.0	121.8
45	271.9	.350	164.6	268.9	91.6
60	287.2	.345	173.6	259.9	73.6
75	298.0	.340	179.5	254.0	61.8
90	306.2	.335	184.0	249.5	52.8
105	312.9	.333	187.6	245.9	45.6
120	317.2	.330	190.0	243.5	40.8
135	320.3	.328	191.6	241.9	37.6
150	322.7	.327	192.8	240.7	35.2
165	325.3	.320	194.3	239.2	32.2

The velocity of the reaction, i.e., the amount of conversion per second, is determined by the tangent to the above mentioned curve. These velocities divided by the product $(NO)^2(O_2)$, should be a constant, the so-called specific reaction rate constant. Such a constant in this experiment would represent the velocity of the reaction when the concentration of both the NO and O_2 is equal to 1 mm. of bromnapthlene.

$$K = \frac{\text{speed}}{(NO)^2(O_2)}.$$

The following results were obtained with a reaction chamber that exhibited $^1/_{8.18}$th of the surface of the vessel used in the preceding experiment:

EXPERIMENT No. 14.

Small surface. Temperature 0°. Initial O_2 pressure 409.9, initial NO pressure 395.9.

Time (sec.)	Δp.	α	x	(O_2)	(NO)
15	114.2	.470	74.6	335.3	246.7
20	163.4	.419	103.3	306.6	189.3
25	189.4	.400	118.2	291.7	159.5
30	209.9	.384	130.0	279.9	135.9
45	243.4	.365	149.0	260.9	97.9
60	262.0	.356	159.4	250.5	77.1
75	274.1	.350	166.2	243.7	63.5
90	282.9	.347	171.0	238.9	53.9
105	289.0	.344	174.5	235.4	46.9
120	293.8	.341	177.0	232.9	41.9

When the reaction is carried out in the vessel exhibiting the smaller surface it is to be noted that 37.7 per cent of the NO was converted in the first 15 seconds, against 51 per cent with the larger surface. This comparison is not exactly fair because the initial concentration of the NO was greater in the case of the larger surface experiment. The two rates may be compared by means of the specific reaction rate constants, which should be independent of the concentration of the reactants.

	$K \times 10^7$						
Time (seconds)	15	20	25	30	45	60	75
Large surface	18.5	7.96	7.41	7.06	7.1	7.1	7.0
Small surface	10.13	7.94	7.14	7.42	6.8	8.0	7.9

From the above table it can be seen that the velocity of the reaction is greater in the case of the larger surface experiment at the beginning of the reaction, but quickly becomes equal to the velocity of reaction in the smaller surface This fact can be much more strikingly shown by means of the velocity curves themselves, furthermore the autocatalytic character of the reaction is immediately seen from the shape of these curves.

Such behavior is much more striking in the case of measurements carried out at the temperature of 30°. This evidence together with the results at the still higher temperatures will be brought out at the reading of this paper.

Summary

1. The rate of oxidation of NO by O_2 has been experimentally studied at temperatures of 0°, 30°, 54°, and 90°.

2. It was found that the initial rate of the reaction was greater in those cases that were studied in large surface reaction chambers.

3. The reaction was of the autocatalytic type.

4. The rate soon became proportional to the product $(NO)^2 (O_2)$, indicating a third order reaction.

5. All the results were explained on the assumption that the reaction took place on the walls of the containing vessel.

6. The experiments of Bodenstein were shown to be faulty in the respect that he failed to notice the correct course of the reaction at the beginning of the experiment.

Discussion

President Howard: It seems to me that this paper is exceedingly interesting, and would have a very great practical bearing on the

mechanism of gaseous reactions, as well as on the design of such apparatus as is suitable for the study of such reactions. I certainly hope that you will carry it out to its conclusion and try it out on a great many different cases.

DR. PATRICK: That is what we propose to do.

PRESIDENT HOWARD: I suggest that when you are exploring the first part of the curve you will consider increasing very largely the size of the stopcocks so that the time they must stay open will be negligible. The paper is open for discussion.

MR. H. K. MOORE: Is heat liberated when you form NO_2?

DR. PATRICK: Yes, the reaction is exothermic.

MR. MOORE: Then if you change an endothermic compound into something different, you should expect a greater rate of reaction at the lower temperature.

DR. PATRICK: Considering the small amounts of gas actually used, it can be calculated that the heat liberated is very small and should not appreciably change the temperature of the reacting gases.

MR. MOORE: In 1910 I conducted some experiments of this kind and I remember that the temperature went as high as 150° C. Inasmuch as the reaction was exothermic I obtained 100,000 times the yield by simply refrigerating the gases. This seems to be a general rule that exothermic reactions are favored by the subtraction of heat. Have you tried refrigeration?

DR. PATRICK: We have made no experiments at lower than 0° C.

MR. MOORE: Have you tried a dynamic method of studying this reaction?

DR. PATRICK: That is the method that was always used before Prof. Bodenstein began his experimental studies of this reaction. Bodenstein pointed out that the dynamic method did not yield correct results. Trautz at Heidelberg has also been interested in this reaction with a view of explaining the very puzzling negative temperature coefficient. He has attempted to apply the quantum theory.

DR. S. KLOSKEY: Dr. Patrick's paper deals with the rate of reaction and not with the question of equilibrium. I think that Mr. Moore has confused these two phenomena. The rate of an exothermic or of an endothermic reaction would still be expected to increase with increasing temperature.

PRESIDENT HOWARD: Is there further discussion? Have you further remarks Professor Patrick?

DR. PATRICK: No.

[Discussion closed.]

NEW AND IMPROVED METHOD FOR BUILDING X-RAY ROOMS

By MAXIMILIAN TOCH.

Read at the Washington Meeting December 6, 1923

In June, 1921, the results of my work on X-Ray of Pigments and of Paintings were published in three issues of the American Art News, at which time I had made several hundred radiographs of all of the pigments and an equal number of radiographs of various paintings. At that time I came upon two laws, part of which I summarized as follows:

1. Every pigment is either opaque, translucent, or transparent to X-Rays, depending entirely upon the thickness of the film.

2. Pigments in which the metallic base has a high atomic weight are more opaque than those of lower atomic weight; as, for instance, the lead pigments, being the most commonly used, are the most opaque, because the atomic weight is 207. Next comes barium, the atomic weight of which is 137. Then comes cadmium, with an atomic weight of 112; zinc, with an atomic weight of 65; and the iron pigments the atomic weight of which is 56.

3. If two paintings are executed on the same ground the radiograph will show them only in relation to their heavy pigments, etc.

Upon making further investigations I found that a few months before my work was published Professor F. K. Richtmyer of Cornell University, published an article in the *Journal of Radiology,* March, 1921, on "The Absorption of X-Rays by Various Media," in which he established a formula for the absorption of X-Rays which is based on the atomic weight of the heaviest element contained, and which bears out perfectly the results that I had obtained.

My experience with X-Rays warrants the assertion that these unseen forces are very dangerous and I have come to the conclusion that we know very little about where they come from or whither they go, yet those who have had to deal with them found out long ago they they must be confined in a lead lined room and that in the construction of a room of this kind such great weight is added that the building must be reinforced in order to hold the large quantities of

sheet lead necessary for the purpose. Yet a peculiar omission sometimes takes place, that while the walls are lined, ceilings or floors are not always lined, and I am reliably informed that there have been several cases, in England, where people working in a room below an X-Ray machine have suffered from pernicious anemia and have eventually died without any other cause having been attributed to their malady.

It is well known that in order to outline the digestive organs, neutral insoluble and otherwise chemically pure barium sulphate is administered internally and in that manner the organs are outlined, because the X-Ray does not penetrate an element of high atomic weight.

It, therefore, occurred to me that an X-Ray room which is being built ought to be plastered with lime mortar to which about 50 per cent of barium sulphate, by weight, is added. This means, to one pail of lime mortar a half pail of barium sulphate is added. In making blocks of mortar containing barium sulphate, to the average thickness of ¾ of an inch, I found that the discharge of the X-Ray did not penetrate.

Doctors have frequently installed X-Ray machines in ordinary offices, and in one such office I had an opportunity of making complete experiments with a machine of very high power. The walls and ceilings were painted three coats of a lead barium paint and no penetration took place with the average exposure. The floors, however, were omitted because linoleum was placed on the floor before paint could be applied, but in laying down sheets of paper which had been coated with lead barium mixtures, it was found that no penetration at these points took place to the floor below.

There is being built at Blythedale, New York, at the present time, an X-Ray room which is not being lead lined, but in which the brown coat, scratch coat and final plaster are admixed with barium sulphate. The walls, ceilings and floors, in addition to this, will be painted with three coats of a lead barium paint, and tests made show absolutely no penetration to any discharge of the X-Ray machine.

The conclusion that will naturally arise will be that a lead lined room is superior to the method which I now propose. I am very frank to admit that a lead lined room is just as good but it is not superior and the enormous weight and the tremendous expense of building a lead lined room is saved.

Explanation of the Experiments Made

(*a*) 1 inch plaster containing 50 per cent of barium sulphate, by weight and not by volume.
(*b*) ½ inch concrete containing 50 per cent of barium sulphate, by weight and not by volume.
(*c*) ½ inch concrete containing 25 per cent of barium sulphate, by weight and not by volume.
(*d*) Varnish paint made with barium sulphate only.
(*e*) Varnish paint made with half white lead and half barium sulphate.
(*f*) Varnish paint made with white lead.
(*g*) ¼ inch concrete block containing 10 per cent oxide of iron.
(*h*) Sheet lead—⅛ inch thick.

Discussion

President Howard: The paper is open for discussion. Are there questions or remarks?

Mr. F. C. Zeisberg: I should like to ask Mr. Toch whether the barium salts show any different stopping effect, from lead, on rays of different degrees of penetrability? We have hard rays that pass through a given material more readily than soft rays, and I wondered whether the barium salts would stop the hard rays equally as well as lead.

Mr. Toch: Naturally I made experiments with all types of X-ray. It is well known that soft rays are stopped by glass, and I determined that that was due to the manganese and iron in the glass. The hard rays are produced usually by additional screans. You can make an X-ray so hard that it will go through an iron casting, and as a matter of fact castings are examined in that manner. I have thousands of photographs showing these same materials with the hard rays and soft rays. Lead stops the hard rays, and if lead stops the hard rays then a sufficient thickness of barium salts will stop the hard rays also.

President Howard: If there are no further questions we will take up the next paper.

THE FUNDAMENTAL PRINCIPLES OF MULTIPLE EFFECT EVAPORATIVE SEPARATION

THE EVAPORATION OF SULPHITE LIQUOR BEING TAKEN FOR ILLUSTRATION

By HUGH K. MOORE

To be read and discussed at the Washington meeting, December 5–8, 1923

At the St. Louis meeting in 1917, I gave before this body a paper on evaporation and drying. In the last part of that paper I touched lightly on some of the phases of multiple effect evaporation. Since then I have had repeated requests to go more into detail as to this part of the paper, and it is in answer to these urgent requests that I stand before you to-day with a paper touching on the same subject.

In travelling about the country I find that there is widespread misconception of the functions of a multiple effect evaporator and in order to clarify these I shall take up the principles involved and illustrate the method of attacking an evaporation problem by giving a specific example, viz., evaporation of waste sulphite liquor.

The usual object sought in multiple effect evaporation is the separation of liquids from liquids or liquids from solids by means of evaporation, which by being conducted in stages reduces the cost of separation to a minimum. In this paper I shall use the term multiple effect separation or evaporative separation, because the term evaporation has been used so long in boiler practice that the term connotes a real evaporation rather than one or more evaporations followed by the same number of condensations. Thus, to find the heat required to evaporate a given weight of water in a boiler you can multiply this weight by the total heat in the steam, assuming, of course, that the water is at 32° F. Such a method, however, would give false results in a multiple effect evaporator for each unit is not only an evaporator but a condenser, and thus many separations may take place by the re-use of the original heat. Evaporative separation connotes a separation taking place as distinguished from other separations, such for instance as magnetic, electrical, centrifugal, gravity.

filtering, flotation, etc., in that the separation is accomplished by evaporative means and the emphasis is entirely on the separation, while the word evaporative simply distinguishes the means. Multiple effect separation also connotes a separation in which the process is carried on in two or more interdependent units and in this article I shall use this term as synonymous with multiple effect evaporative separation, or multiple effect evaporation.

Multiple effects are seldom employed except where the quantity to be separated is so large as to make the saving of fuel required for the separation of considerable importance. In attempting to solve any evaporative problem there are certain fundamental questions to be asked and I will give some of these.

1. What metals are not attacked by this solution?
2. On evaporation does it tend to foam in any of its stages?
3. Does it deposit solids during evaporation?
4. Does it tend to form scales on heating surfaces?
5. Does it dissociate so as to give off permanent gases?
6. If so, is this dissociation caused by concentration, local overheating, or long time contact with hot surfaces?
7. Does it dissociate so as to give off corrosive gases?
8. Does it polymerize with heat?
9. Is cost of evaporation a controlling factor?

The choice of the type of evaporator to be used will depend largely upon the answer given to the above questions. In this article my object is to show the method of attack and to do so it will be necessary to take some specific liquor, which in this case will be waste sulphite liquor. And applying the above questions to this we find that (1) after neutralizing it does not appreciably attack iron, (2) it tends to foam abominably at low concentrations, (3) it does not deposit solids in the true sense of the word, (4) it may or may not form scale, (5) it tends to dissociate, giving permanent gases, (6) long time contact and local overheating with hot surfaces has a much greater effect on its dissociation than concentration, (7) this dissociation tends to give off SO_2 gases, (8) it does not tend to polymerize, and (9) the cost of evaporation is the controlling factor.

From the above it will be seen that the evaporator must be so designed as to remove scale if formed. The absence of depositing solids does not confine us to a certain type but gives us a large leeway. The construction must be such as to keep foam from causing

a loss and becoming a nuisance. The contact with heated parts must be reduced to a minimum and means must be provided so that the corrosive gases shall not be formed or that they shall be neutralized when formed. On account of cost we must avail ourselves of every device to obtain maximum efficiency of evaporation even if it adds considerably to the original cost of installation. To me this connotes some evaporator which must have the advantages of the film type evaporator, and that the liquor must be on the inside of the tubes in order to facilitate the removal of any scale which might happen to be formed.

The above questions and answers are so apparent to the chemical engineer that no more time need be taken in discussing them.

We now come to the question as to what are the fundamental considerations in evaporation? I have been asked this question so many times that I feel that I shall have to go into this matter in considerable detail for the many, even at the risk of being tedious to the few who are familiar with the subject. The more important of these considerations are:

1. Temperature spread.
2. Individual temperature differences (including rise in the boiling point).
3. Static head of liquor over heating surfaces.
4. Viscosity of liquor at different concentrations and at different temperatures.
5. Velocity of liquor over heating surfaces.
6. Specific gravity.
7. Boiling point.
8. Prevention of corrosion.
9. Temperature levels and heat conductivity.
10. Sequence in evaporation.
11. Elimination of condensation.
12. Elimination of entrained air and non-condensable gases.
13. Elimination of steam from liquor so as to avoid foaming.
14. Keeping conducting surfaces wet.
15. Keeping surfaces free from incrusting matter.
16. Mechanical construction.
17. Number of effects.

Temperature Spread.—Temperature spread in an evaporator is the difference in temperature of the initial steam and the final steam

going to the condenser. In designing an evaporation plant the chemical engineer is often called upon to design an evaporator which will fit in with existing conditions in the mill, viz., the condensing water may be limited in amount, or it may rise to a high temperature during certain seasons of the year, or the steam available may be at low pressure, or there may be a limit to which the substance can be heated or a limit to which the liquor may be cooled, and there may be many other considerations which will readily occur to you all, but which I will not consume your time to mention. If the condenser water goes to 85° F. in the summer time you have limited the temperature of the steam going to the last effect to 25° above the limit if the condenser water is 60°, other things being equal. (This is a general statement however, for there may be limitations on the vacuum pump which may modify this to a certain extent.) If the amount of condensing water is limited, you may have to heat it hotter than you would like and a temperature limit is again set below which you can not go. On the other hand you may have exhaust steam or live steam, and so you may be limited on this end also.

Thus, assume two cases, one with initial steam at 100 lbs. gage pressure and steam to the condenser at 2″ absolute pressure, and the other having the initial steam at 5 lbs. gage pressure, with vapor going to the condenser at 6″ absolute pressure. In the first case there is a possible temperature spread of 228° F. while in the second case the spread is only 88° F. It will be seen from the above that the evaporative engineer may be seriously handicapped from the start. For in the first case he could use large temperature differences between each effect, and a small evaporator or more effects with a small temperature difference between each, while in the latter case he must confine himself to a very few effects with a large temperature difference, or if he increases the number of effects the temperature difference between each will have to be so exceedingly small that he will require an evaporator of enormous size. This must be so self-evident that no further attention will be given this phase of the subject and we will pass on to that phase of the subject in which the allowed temperature spread may be the same. Under these conditions the greatest economy will be in that evaporator which utilizes the least part of this allowed temperature spread, other factors of course assumed to be equal. To illustrate this point I submit two charts, Figs. 1 and 2, which are calculated on a theoretical basis, all

factors considered equal with the exception of the temperature spread, which is, of course, governed by the individual temperature difference. In these charts loss by radiation will not be taken into consideration; first, because this factor is largely within individual control, and, second, because this is governed by too many factors to be considered in a general discussion of the principles of evaporation, in which size, surrounding temperatures and the individual temperatures of each effect, etc., are not considered; though, of course, it will be readily seen that the lower the average temperatures, the lower is the heat lost from this cause. What we wish to show is that if by some means or other we can get a higher heat conductivity per square foot of heating surface and thus lower the individual temperature differences, and thus the total temperature spread, we can with the same size of evaporator, other things being equal, obtain a greater economy in that evaporator which has the lowest temperature spread. Also, I want to state right here, that as in this discussion we are to consider several variables, and that inasmuch as the only way to see the effect of any one variable is to keep all the others constant, unless I specifically mention a departure from this procedure, it must be understood that the above method will be adhered to, irrespective of whether or not I mention it specifically in each particular case.

Inasmuch as we must start somewhere I am going to assume as a basis 1,000 lb. of solids whose specific heat is 0.5, in a water solution such that the percentage of solids will be 8.54 per cent, that the temperature of the liquor is 160° F., the number of effects six, the temperature spread allowed 120°, with the steam going to the condenser at 100°, and concentration to 50 per cent. Rise in boiling point or radiation will not be taken into consideration and as tabular data for calculation of the charts would consume much space, only those absolutely essential will be included. In Fig. 1 is shown (A) forward or parallel flow evaporation, using a temperature difference of 20° F., (B) the same with a temperature of 10° F. In Fig. 2 is shown (A) backward or counter-current flow with a temperature difference of 20° F, and (B) the same with a temperature difference of 10° F.

A study of these charts will show that by decreasing the temperature spread from 120° to 60° we have raised the ratio of water evaporated to steam used from 6.18 to 7.67 in the case of forward

evaporation, and 5.49 to 6.02 in backward evaporation. It will also be noticed that the amount of steam to the condenser is decreased in both cases.

In the above theoretical examples we have assumed a uniform temperature difference of 20° F. in A, Fig. 1 and Fig. 2, and a uni-

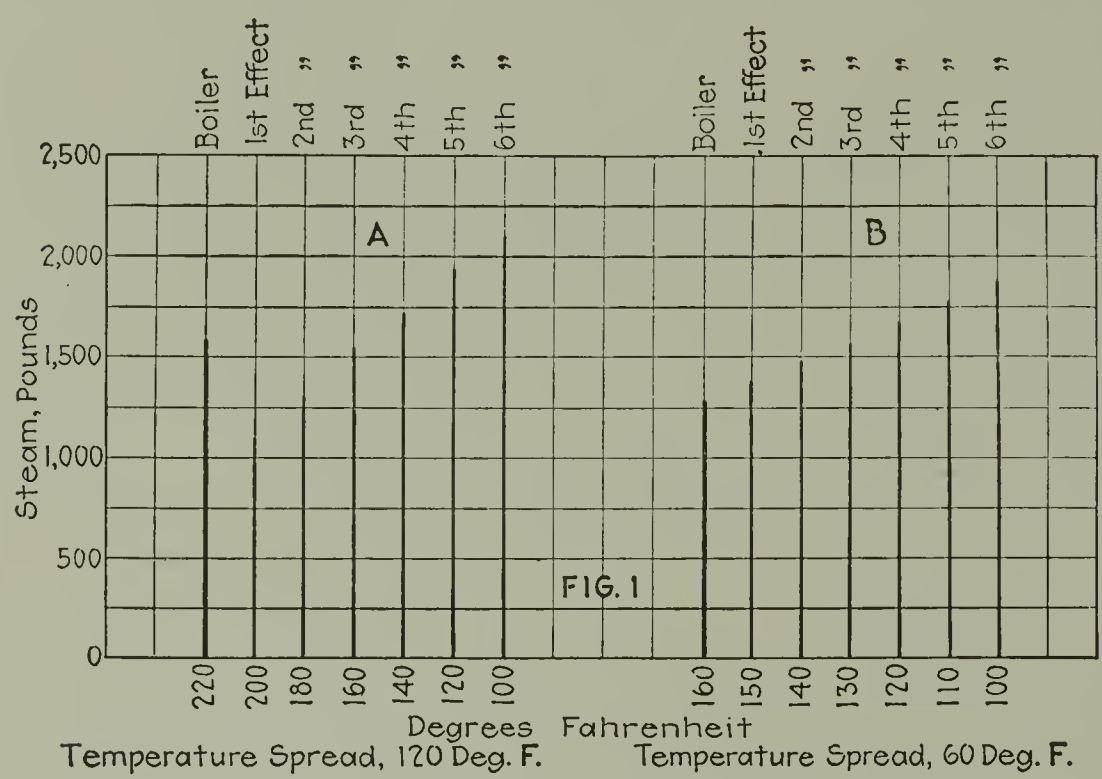


Fig. 1

form temperature difference of 10° F. in B, Fig. 1 and Fig. 2. Such uniform temperature differences rarely, if ever, occur in actual practice and the charts are only submitted to show a principle which every evaporative engineer must take into consideration, if he is to design an evaporator which will operate at the greatest efficiency.

(2) *Individual Temperature Differences.*—In order to reduce the total temperature spread, it is self-evident that we must reduce the individual temperature differences between the heating steam on one side and the liquor undergoing evaporation on the the other side, and to accomplish this progressively evaporative engineers have given this subject much time and thought. It is my intention to call attention to the various factors which must be considered. The first natural impulse is to say, increase the heating surface. Unfortunately, the solution does not lie with so simple a remedy, for by doing so you increase the first cost, increase the cost of maintenance

and repairs, increase radiation losses and fixed charges, to say nothing of the chances of increasing leaks and the cost of labor. We, of course, have no other course when we are dealing with large capacities in comparison with small capacities, but what we are primarily interested in is the greatest efficiency at the minimum cost.

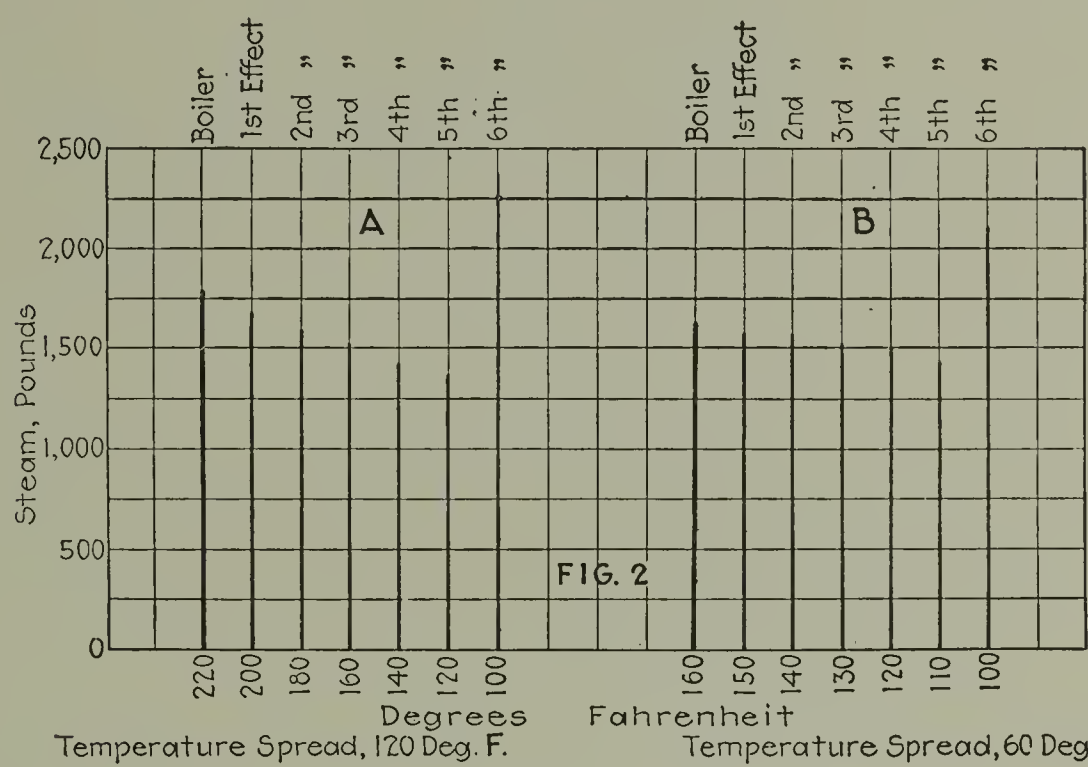


FIG. 2

(3) *Static Head.*—The first of all requisites is to get rid of static head. Let us discuss this subject in relation to evaporation. In evaporators of small capacity this subject may not assume great importance, though even there it may be appreciable. Let us assume that the pressure in the last effect is 2″ absolute or 28″ vacuum.

Let us assume for instance that in the last effect we have a static pressure equivalent to 1″ of mercury over the lowest part of the heating surface. This static head amounts to 1.13 ft. of water and corresponds to a difference of 14° F. in temperature, the difference between 2″ absolute pressure and 3″ absolute pressure. It will readily be seen that if only 10° F. difference of exchange is used, under these conditions hardly any heat at all will be transmitted through the lower heating surface because the static head of 1.13 ft. of water raises the boiling point 14°, while we have only 10° leeway and the only heat transmitted is that used in heating the liquor. In fact, if we stick to 10° difference of exchange we find that only 0.79 feet of

water will correspond to a static head of 10°. In most solutions, however, we have a liquor of a much higher specific gravity than water. Let us assume a specific gravity of 1.3, then we find that 0.61 ft. of this solution will correspond to 10° of temperature difference. Now if this difference of 10° F. is to be maintained we find that the depth of the bottom heating surface can be only 7.3″ below the surface of the liquor, with the bottom heating surface hardly functioning at all. If large capacities are to be obtained, the only way of obtaining such is to increase the length and breadth, which means costly construction subject to mechanical weaknesses, with an enormous increase of radiating surface, or we may increase the heating surface by increasing the number of units, which procedure is in its effect the same as in the first alternative.

Now let us suppose that the capacity has to be so large as to require a difference of 12 feet between the bottom and top heating surface, and let us assume the liquor has a specific gravity of 1.3; we find this is equivalent to 15.6 feet of water, or 13.8″ of mercury, which corresponds to a temperature difference at the bottom of 81° F.; the bottom heating surface even with this enormous difference of exchange scarcely functions in evaporation though it may heat the circulating liquor, and we find the static head has made in this effect alone a difference of more than eight effects. Again, this temperature difference of 81° F. corresponds to 15.8 absolute pressure, inasmuch as we have assumed an absolute steam pressure to the condenser of 2″ absolute (28″ vacuum, barometer 30″) which corresponds to a temperature of 100° F. Now let us again, on the preceding effect, assume a static head of 12′ with a specific gravity of 1.25. We then have an absolute pressure of 29.1″ (0.9″ vacuum, barometer 30″) or a boiling point at the bottom heating surface of 211° F., and we have lost 30° F., corresponding to 3 effects of 10° temperature difference each, and yet only two effects have been used. These illustrations show that in evaporation a large unit may be less efficient than a small unit, and thus quite different from most operations where the reverse is more apt to be true. It will thus be seen that the elimination of all static head is desirable as one of the positive means of reducing individual temperature differences and consequently the total temperature spread.

(4) *Viscosity.*—In the above charts I have assumed a constant temperature difference, but such rarely occurs in practice. First,

because most liquids tend to increase in viscosity, and, second, because the amounts of heat transferred in different effects vary. The more viscous the liquor, the less is its conductivity, as a rule. The reason for this is that most liquids are poor conductors of heat and that most of the heating of such is accomplished by heating the individual molecules. The greater the number of molecules coming in contact with the heated surface, the greater is the heat transferred. The more viscous the solution the less is the transfer of heat, for the number of molecules coming in contact with the heated surface in a given time diminishes with increasing viscosity. Most solutions, however, tend to become less viscous as their temperatures are increased; from which fact it would appear that an evaporative process should be conducted in such a way as to neutralize the tendency to greater viscosity due to concentration by an increased temperature, unless other considerations make it inadvisable. To illustrate how the viscosity may change with temperature, I submit Fig. 3, a viscosity-temperature chart of waste sulphite liquor. The values are obtained from a Stormer viscosimeter. It will be noted from this chart that the viscosity of waste sulphite liquor up to 29 per cent varies little from that of water, and that an increase of temperature decreases the viscosity only slightly. When, however, we come to deal with a 50 per cent waste sulphite liquor we find that the viscosity is many times greater than either water or sulphite liquor of concentrations less than 30 per cent, while at high temperatures it may be only four times that of these other liquids. The logical course of evaporation of this liquor, provided we do not have other interfering considerations, would be to have the concentrated liquor emerge from the evaporator which is at the highest temperature.

(5) *Velocity of Liquor over Heated Surfaces.*—It is a well-known fact that with increase in velocity over the heated surface we get an increase in heat transfer. Inasmuch as this laboratory has already made a contribution to this organization,[1] in which this matter is discussed at great length, I shall not again go into it here, but bearing this in mind it will be seen that we must consider this factor when we come to evaporator design. Especially is this true when the liquor is so viscous that the only way of getting a high heat conductivity is to get a high velocity over the heated surfaces.

[1] G. A. Richter, *Trans. Amer. Inst. Chem. Eng.*, 12, II, 147–79 (1919).

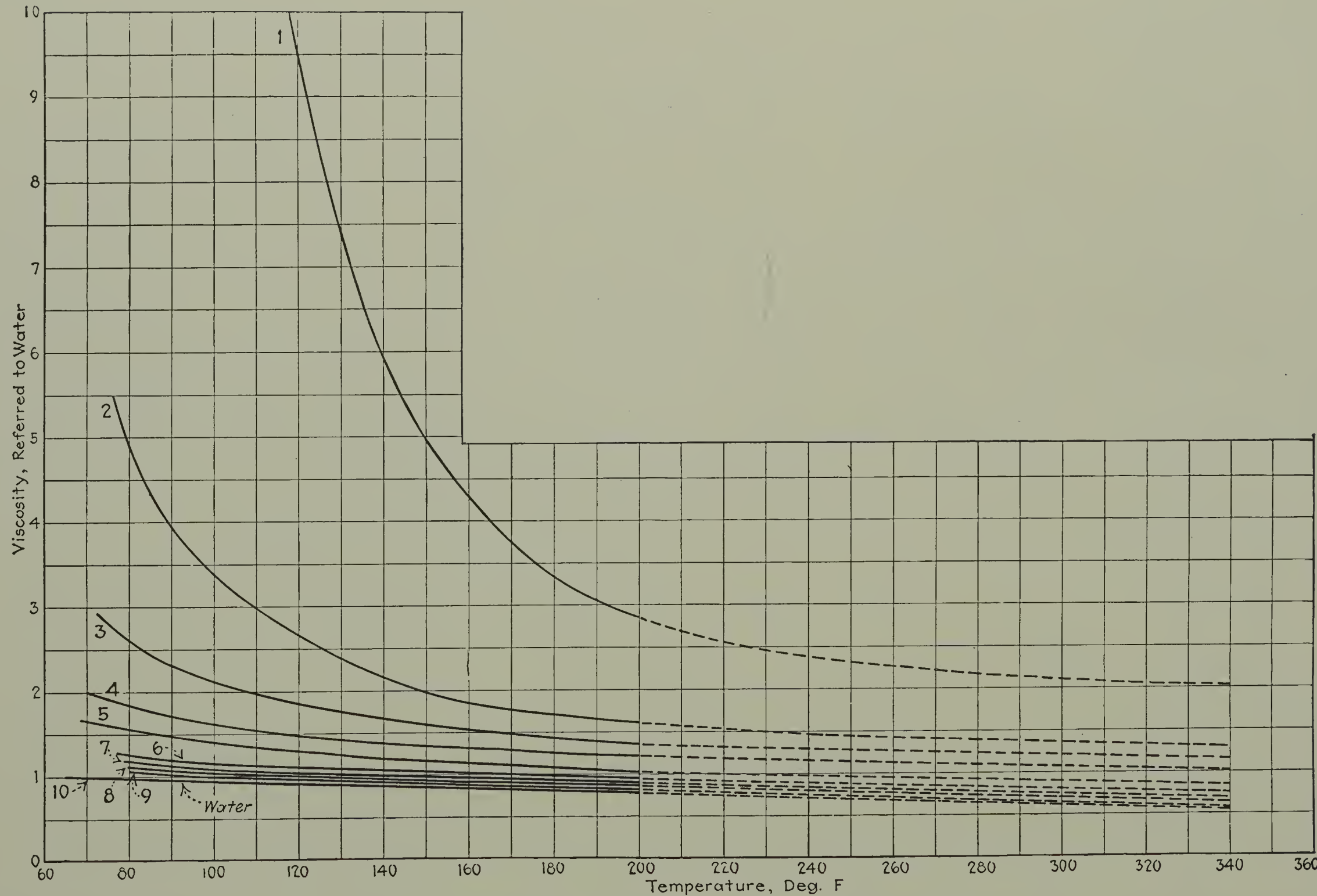


Fig. 3. Viscosity-Temperature Chart—Waste Sulphite Liquor.

(6) *Specific Gravity.*—The same considerations which we have taken into account in relation to viscosity, and velocity, apply in many cases to specific gravity. Thus, a highly attenuated gas, such as

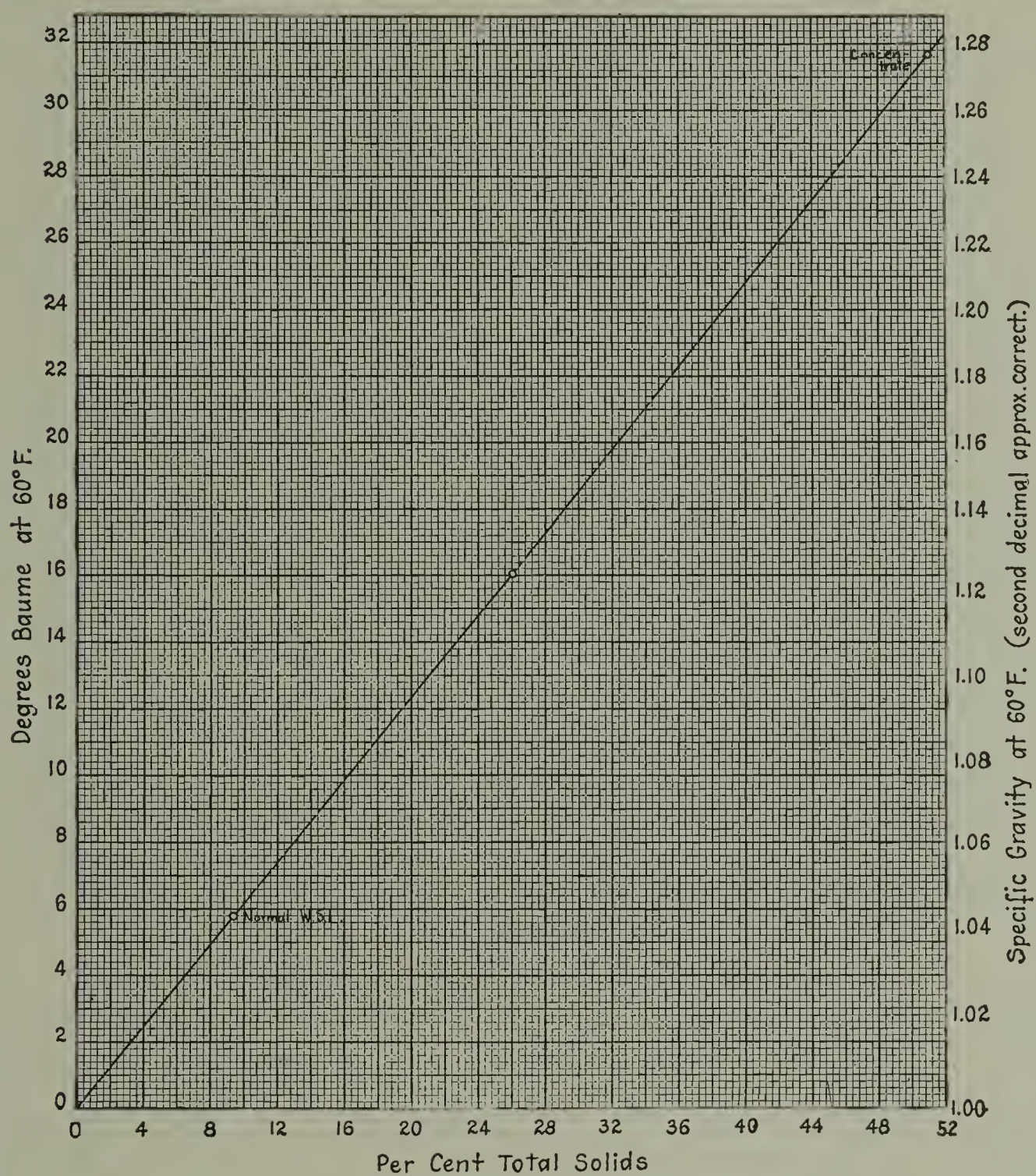


FIG. 4.

steam in the last effect of an evaporator (vacuum end), will move a light, mobile body over the heated surfaces much faster than a heavy viscous body, and as before stated, the greater the velocity the greater the heat conductivity. Inasmuch as we are dealing with waste sulphite liquor I submit Fig. 4 showing the concentration chart of this

liquor in terms of specific gravity and degrees Beaumé and Fig. 5 showing the effect of temperature on the specific gravity of this liquor.

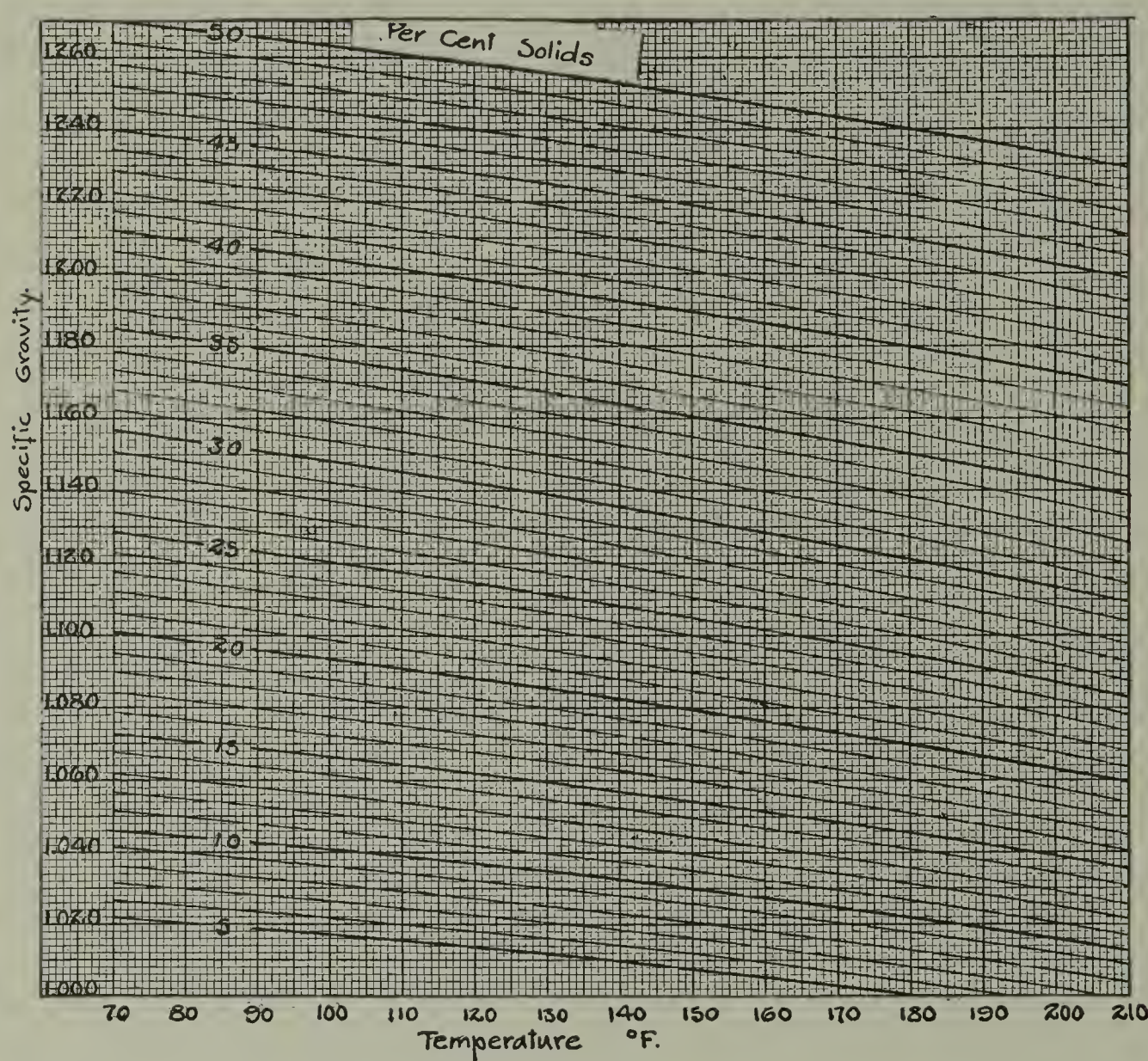


FIG. 5. Concentration Chart for Waste Sulphite Liquor. Specific Gravity of Liquors containing from 5 Per Cent to 50 Per Cent Solids, at Temperatures from 70° to 210° F.

(7) *Boiling Point.*—The individual temperature differences may be greatly affected by the rise in the boiling point. According to the law of molecular rise in boilng point we know that the rise in the boiling point is according to the increase in the number of molecules in the same amount of solvent; but in commercial evaporation problems the rise may be small or large, according as to whether the dissolved substances tend to polymerize or dissociate still further. Furthermore, a 50 per cent solution containing a substance of large molecular weight may not have as high a boiling point as a

25 per cent solution containing a substance of small molecular weight. Furthermore, the boiling point may be influenced by the kind of solution. If it is colloidal the boiling point may not rise to the same extent as would be the case if we had a true solution. The knowledge of this is important for this point alone may determine

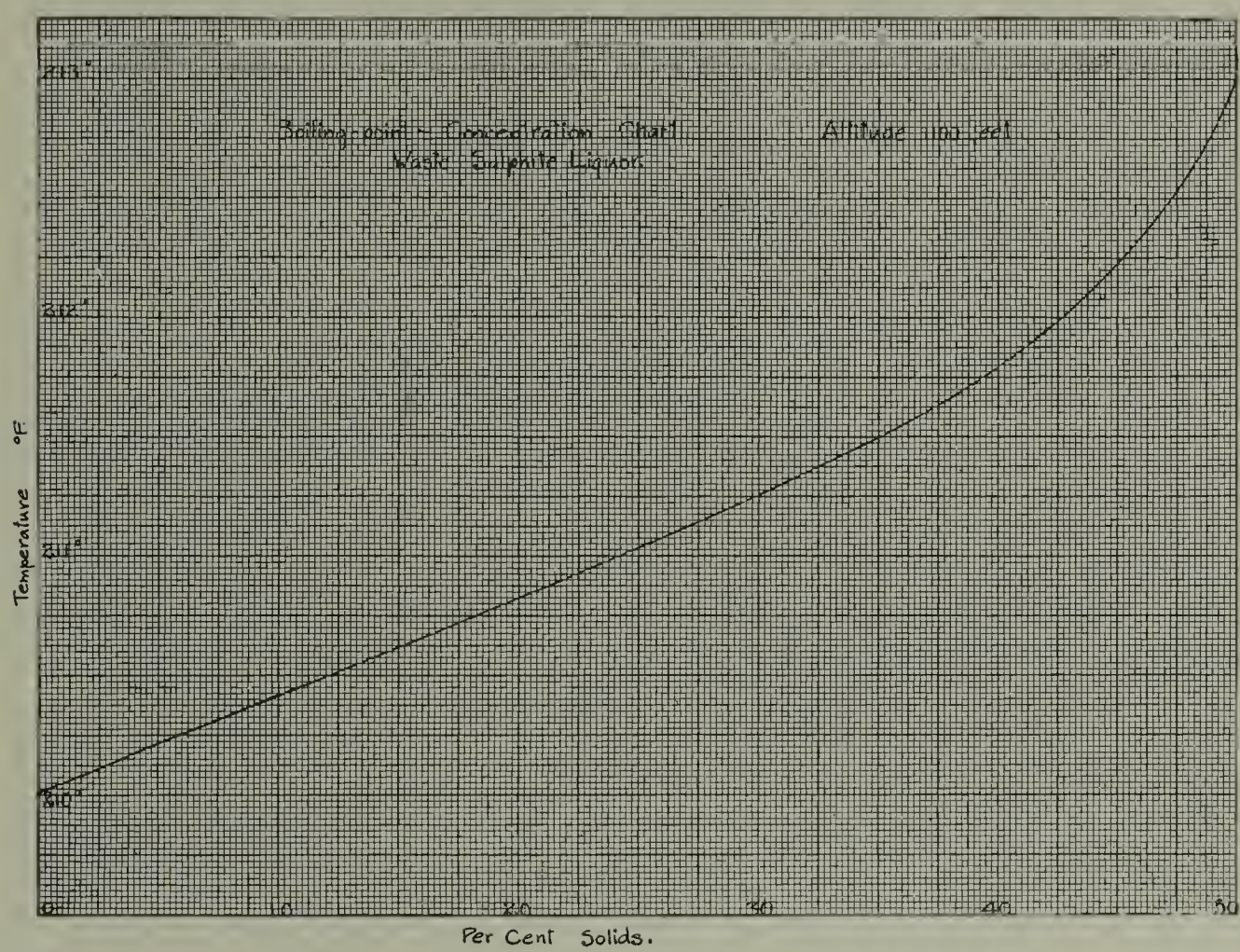


FIG. 6. Boiling-point-Concentration Chart. Waste Sulphite Liquor. Altitude 1,100 feet.

the nature of the evaporating process. I include Fig. 6 showing the rise in boiling point in concentrating waste sulphite liquor. It will be seen that the rise in the boiling point of sulphite liquor is only 3° F. I might add that the rise in the boiling point of sulphate liquor is 10° F.

In order to avoid repetition I shall illustrate how the rise in the boiling point may affect the process of evaporation when I discuss prevention of corrosion of tubes.

(8) *Corrosion of Tubes.*—Certain liquors have an acid radical which is so lightly held that long time contact with heated surfaces may liberate the radical with the tendency to corrode the tubes. In such cases the difficulty may be eliminated either by so conducting

operations that the time element may be reduced to a fraction of a second, or a sufficient amount of alkali may be added to anticipate this dissociation. The deciding factors will be cost and quality of resulting product. We have two alternatives before us: we may feed each effect of a multiple effect evaporator from a common source so that weak liquor enters each evaporator and we may take a concentrated solution from each evaporator. That is, the liquor goes through each effect in parallel instead of going through them in series, viz., from one effect to another, or we may pass the liquor through all, neutralizing it enough in one operation or in proper stages. If the rise in the boiling point is large the first method may so increase the individual temperature difference and thus increase the total temperature spread, as seriously to detract from the efficiency. It furthermore may defeat its own ends by raising the temperature in the first effects enough to neutralize the advantage sought. If the rise in the boiling point is low we may adopt this method without serious loss in efficiency. If the liquor is of such a nature that neutralization will be detrimental the parallel flow method may offer a way out of this difficulty.

(9) *Heat Conductivity, Temperature Levels, and Temperature Differences.*—It has been known for many years that the heat transfer per square foot per degree of difference increases with the temperature difference and temperature level. Classen pointed this out years ago and recently W. L. Badger has again called attention to the same fact, but this one fact does not help us much unless we have the constants for the particular liquid under consideration. Furthermore, these values differ even for the same liquid according to the type of the evaporator and the conditions under which it operates. It is fundamental, then, that these constants should be determined for the liquor under consideration, under the same conditions it will be subjected to under actual operation. But as the determination of these constants is for the purpose of establishing the conditions of operation which are not known, we find it necessary to determine a large number of constants. Figs. *7a–7e* show the heat conductivity of five different concentrations of sulphite liquor, viz., 10 per cent, 20 per cent, 30 per cent, 40 per cent, and 50 per cent solids at different temperature levels and different temperature differences. There is no static head on the liquor, the velocity of the liquid is that obtained in practice, and the other conditions are practically those of commer-

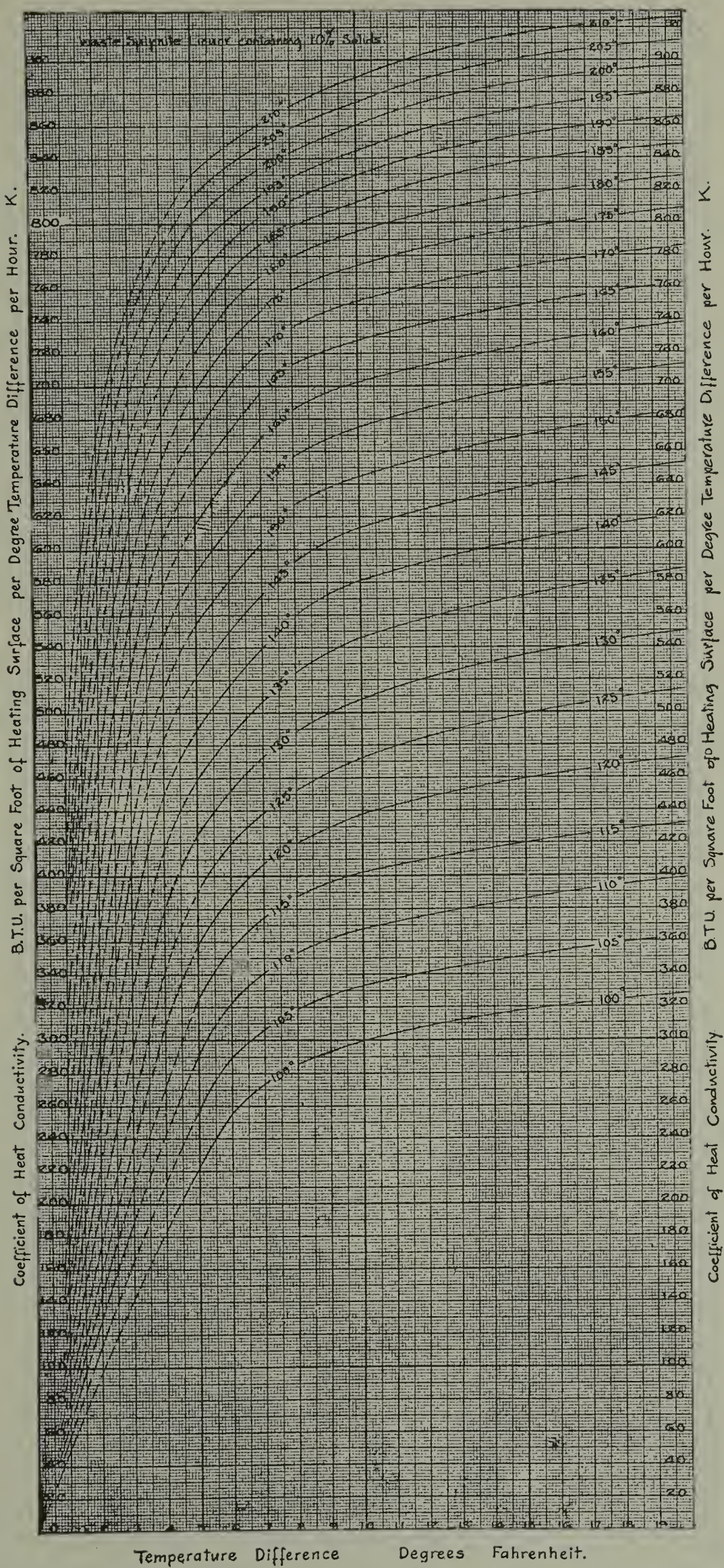


FIG. 7A. Waste Sulphite Liquor containing 10 Per Cent Solids.

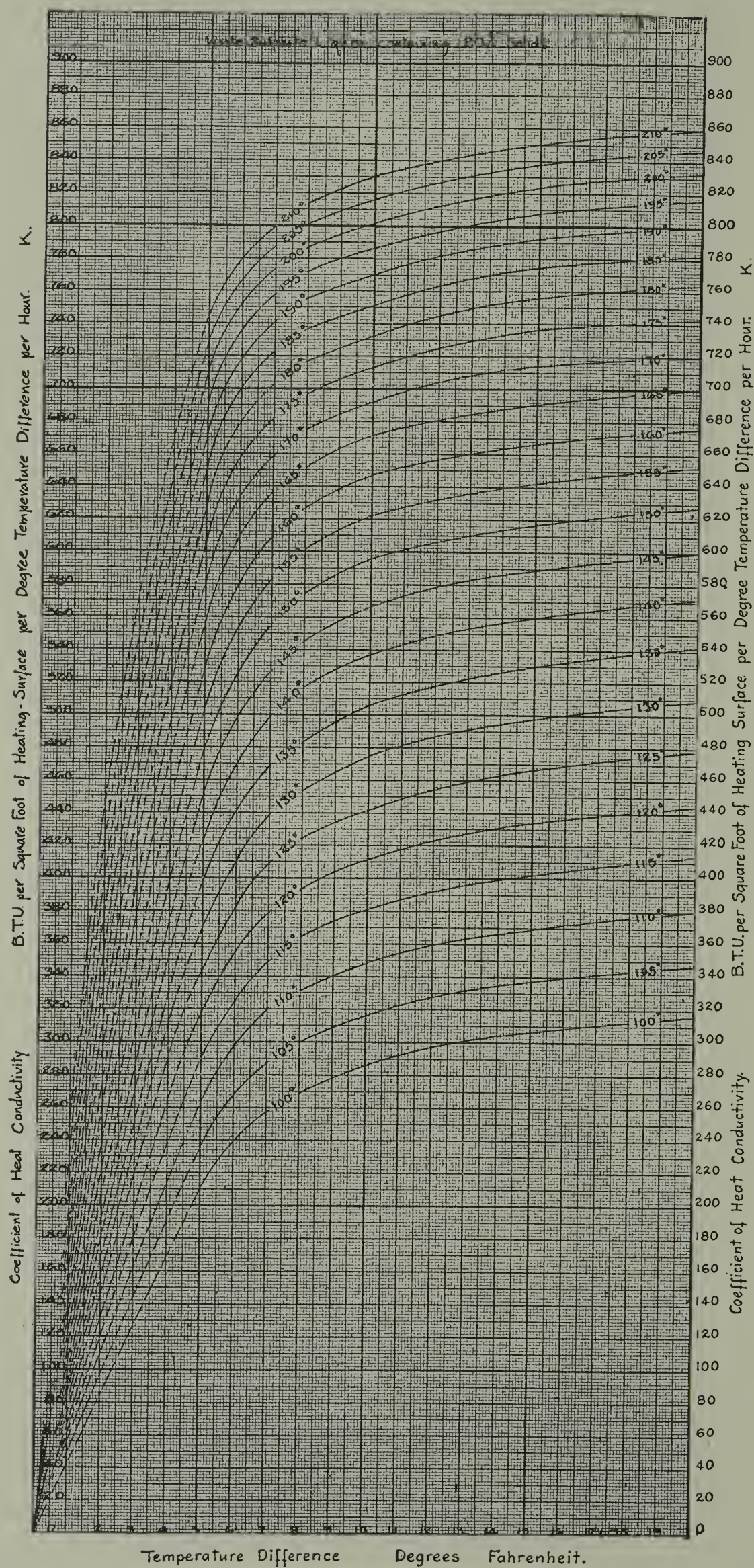


FIG. 7B. Waste Sulphite Liquor containing 20 Per Cent Solids.

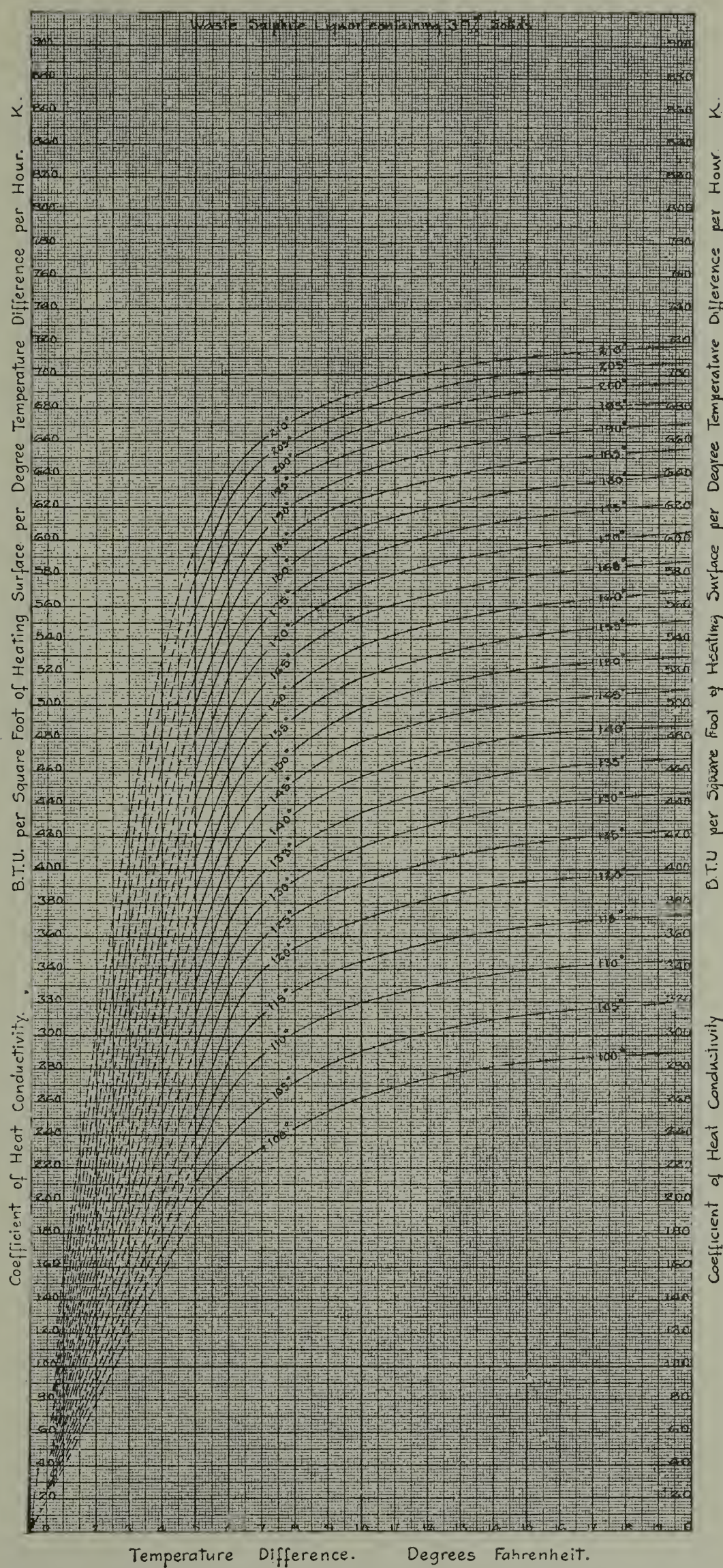


FIG. 7C. Waste Sulphite Liquor containing 30 Per Cent Solids.

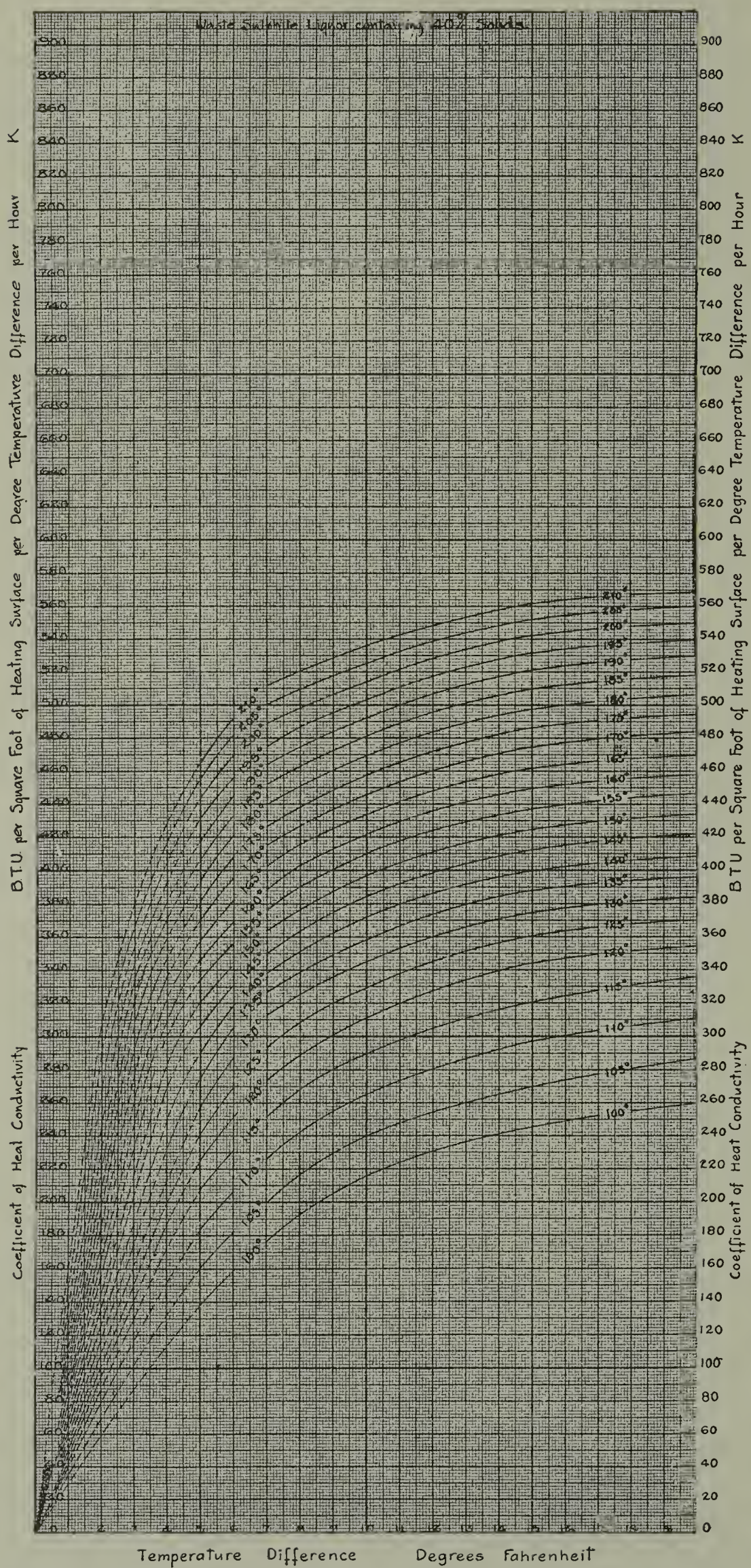


Fig. 7D. Waste Sulphite Liquor containing 40 Per Cent Solids.

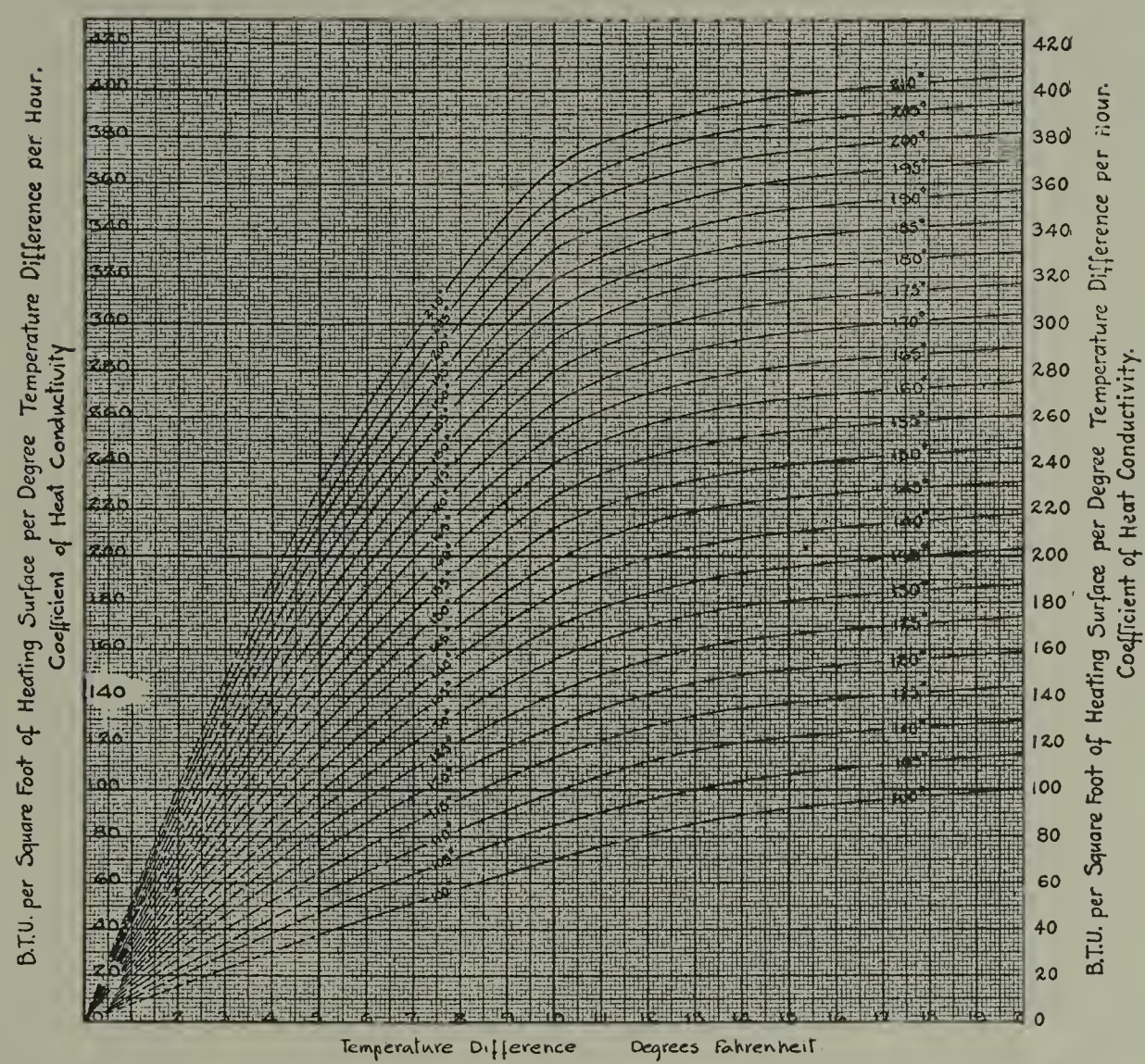


FIG. 7E. Waste Sulphite Liquor containing 50 Per Cent Solids.

cial practice. These experiments and others have been conducted over a long period of time and the curves are those actually obtained from thousands of figures. In relation to the above chart, I wish to call attention to the fact that I have no confidence whatsoever in the accuracy of those parts of the curve which lie between zero and 5° difference of exchange. In the first place I am not certain that they go through zero at all. In the second place, the errors of observation due to the personal equation and many other factors, are so great and the results differed so markedly under what we thought to be identical conditions that the plotting of the same became a matter of individual opinion. Above 5° these points fell more evenly on the curves indicated, except in a few cases, where the cause of the discrepancy was an obvious error. Above 10° the curves may be considered absolutely accurate. Such being the case it might have been more logical to have left out that portion of the curves which lie

between zero and 5° temperature difference. The curves, it will be noted, head downward, at a very rapid rate and we may assume that those portions just under the 5° mark are sufficiently near the truth as at least to give some idea of the truth, if we do not want our possibility of error confined within too narrow limits. I make this statement not only on the grounds of accuracy, but also to save trouble for those who may be tempted to use these charts for the information contained therein, rather than to determine charts of their own under their own particular conditions. And here I may say that the experiments upon which these charts are founded have been conducted under the most critical conditions possible. The pressures were determined in all cases by mercury columns and corrected by the barometer readings. The temperatures were taken by thermometers of proved accuracy immersed in a mercury well, it being found impracticable to immerse them in the liquor or steam itself on account of the other and greater errors which would be introduced by such a procedure. Superheat, entrained moisture, radiation, etc., were all taken into consideration. I wish also to call attention to one error which is liable to creep unnoticed into determinations of this kind. It is not generally known that solutions slightly acid or slightly alkaline give much more uniform results than solutions exactly neutral. Among our experiments we carried on a series in which the liquor to be evaporated was pure water and in doing so we found so many discrepancies that we were forced to abandon the same or abandon the critical nature of the determinations. The variation in heat transfer under what apparently seem to be the same conditions may vary from a few B.t.u. per square feet per degree of temperature per hour to hundreds of B.t.u. per square foot per degree of temperature difference per hour, under identical temperature levels and differences of temperature exchange, and these variations are so great a part of the total when under 5° that, as stated before, I place no reliance whatsoever on the results obtained. For example, shutting down over night may allow an infinitesimally thin film of oxide of iron to form on the steam side of the tube, as well as the inside of the tube, which thin film may be, and is, a poor conductor of heat so that large variations occur. In fact, the air in the steam from the boiler may from this alone cause a loss of heat conductivity to a greater extent than all other factors combined. Be-

cause of this we find that before starting an experiment we must ascertain that the heat conductivity on a standard solution is equal to the maximum obtained when it is known all conditions are ideal. This particular difficulty is largely confined to the first effect, for the entrained acids or alkalis carried over with the steam, slight as they are, apparently overcome this defect. For this purpose a thermo-compressor may be valuable on the first effect; it is, in fact, the only advantage which is completely lost sight of in treatises on this subject. Indeed, I have never seen attention called to this point. But this is not a discussion of thermo-compression, so let us return to our subject.

If you refer to Fig. 7 you will note that the heat conductivity diminishes with the increased percentage of solids, for the same temperature difference and the same temperature level, as well as the decrease in temperature difference. In calculating an evaporator these charts are very essential. In Chart I (*A*) I have assumed arbitrarily a uniform temperature difference of 20° and in Chart I (*B*) we have also assumed arbitrarily a uniform temperature difference of 10°. This was done to illustrate the economy of reducing the temperature spread. Of course, if we adhere to such an assumption it simply means that the effects will vary one from another in the heating surface, for having fixed the amount of evaporation, the temperature differences and thus the temperature levels, while we constantly increase the concentration, we have left no other course to pursue, for Fig. 7 shows us that we must not only get a decrease in heat conductivity due to concentration, but also must get a decrease of heat conductivity due to lowering the temperature level. Let us see how this works out. Simple calculations will give the percentage of liquor in each effect and the amount of heat transferred in each effect. Now, if we assume this to be sulphite liquor evaporated under the conditions similar to those experiments upon which Fig. 7 is based, we shall then by using Fig. 7 for conductivity figures be able to calculate the heating surface in each effect simply by dividing the total heat conducted by the product of the temperature differences and the conductivity. To illustrate, I submit Table I-*A* for Chart I-*A* and Table I-*B* for Chart I-*B*.

Now a study of these tables shows that the total heat conducted in Table I first decreases in No. 2 effect and then rises steadily to No. 6 effect. This is owing to the large temperature spread, in

TABLE I–*A*

FORWARD EVAPORATION

Liquor enters 160° F., contains 8.54 per cent solids, whose sp. ht. is 0.5. Temperature spread 220° to 100° F. (no allowance made for radiation or rise in boiling point). No hydrostatic head, basis 1,000 lb. solids. (See Fig. 1-A.)

	Boiler	1st Effect	2d Effect	3d Effect	4th Effect	5th Effect	6th Effect
Temp. diff., ° F.	.....	20	20	20	20	20	20
Steam from....	1,570	1,092	1,310	1,528	1,732	1,928	2,118
Per cent solids leaving.....	.....	9.42	10.76	12.86	16.52	24.30	50.00
Head conducted	.....	1,515,000	1,099,400	1,350,240	1,610,440	1,864,000	2,120,640
Temp. level, ° F.	.....	200	180	160	140	120	100
Conductivity K.	.....	980	880	746	588	438	100
Heat conducted ÷20 K.....	.....	77	62	90	136	213	1,060
Heat conducted	.....	5,549	4,028	4,945	5,898	6,826	7,766
Average heating surface.....	206	199	194	187	179	168	100

Total heating surface 1638 sq. ft. Average heating surface 273 sq. ft.

which a large amount of heat is used in heating the liquor in No. 1 effect so that the minimum amount of steam is evolved. In No. 2 effect we get, in addition to the latent heat of the steam from No. 1, effect an added increment of heat from the drip. That heat stored

TABLE I–*B*

FORWARD EVAPORATION

Liquor enters 160° F., contains 8.54 per cent solids whose sp. ht. is 0.5. Temperature spread 160° F. to 100° F. (no allowance made for radiation). No hydrostatic head, basis 1,000 lb. solids. (See Fig. 1-B.)

	Boiler	1st Effect	2d Effect	3d Effect	4th Effect	5th Effect	6th Effect
Temp. diff., ° F.	.....	10	10	10	10	10	10
Steam from....	1,265	1,371	1,473	1,572	1,668	1,765	1,859
Per cent solids leaving.....	.....	9.68	11.28	13.71	17.77	25.90	50.00
Heat conducted	.....	1,268,000	1,392,650	1,517,360	1,643,090	1,766,810	1,994,490
Temperature level, ° F.....	.....	150	140	130	120	110	100
Conductivity K.	.....	698	610	525	423	336	70
Heat conducted ÷10 K.....	.....	182	228	288	389	526	2,849

Total heating surface 4,462 sq. ft.

up in the liquor gives some self-evaporation but is not conducted through the tubes. In Table I-*B* we do not have this marked drop in No. 2 because no heat from the initial steam is stored up in the liquor.

In both tables it may also be noted that the heat conductivity constantly decreases with the concentration and decrease in temperature. Also, in Table I-*A* the least amount of heating surface is required in No. 2 effect while in Table I-*B* the least amount of heating surface is in No. 1 effect. It will also be observed that the ratio of the maximum heating surface to the minimum in Table I-*A* is 17.1 to 1 while in Table I-*B* this same ratio is 15.6 to 1, but that the total heating surface in Table I-*B* is 2.72 times that in Table I-*A*.

Now, of course, it is unnecessary to add that evaporators are not built this way commercially, for to build each evaporator different from any of the others necessitates new patterns and special work, thereby increasing the cost enormously; furthermore, such construction would be valueless even if made, as it would more or less tend to retard improvements in processes, which might change the initial concentrations of the liquor, initial temperatures, and other variables. Commercial practice requires that the evaporators shall be built standard and uniform, compensating for the variables of total heat transfer and heat conductivity by variations in the temperature difference which, of course, affects temperature levels, total temperature spread, concentrations, conductivities, etc., I am aware, however, that oftentimes the last effect is made larger than the others.

The above examples were given only to illustrate the effect of temperature difference and temperature spread, and for this reason only. Had I given an example in which I changed all the factors, the effect of a change in this variable would not have been apparent in the change caused by so many variables.

In Fig. 1, I have shown the relation of steam consumption to the temperature difference and thus total temperature spread. This was in forward or parallel flow evaporation. In Fig. 2, I have shown the same but with backward flow or countercurrent evaporation. In Fig. 2 it will be noted that while there is a saving in steam consumption, it is not nearly so great as in Fig. 1. This is owing to the fact that all the effective original heat above 100° F. is lost in the condenser so that we only get a more efficient use of the heat in the original steam. In Fig. 1 we get not only a more efficient re-use of

the heat in the original steam but also a more efficient use of heat originally in the liquor. With liquor at 160° F. the method shown in Fig. 2 would not be used because of the waste caused thereby in comparison with the method used in case I. If the original liquor was at a temperature of 100° or below, this method would certainly be used, for then there would be a considerable saving (see Chart 10, original article, *Trans. Amer. Inst. Chem. Eng.*, 10, 388 (1917)) and also a saving due to lessened viscosity. In Fig. 1 the temperature of the liquor decreases as the concentration increases. All of these factors tend to decrease the heat conductivity. I am, therefore, tempted to submit Tables II-*A* and II-*B* illustrating Fig. 2, and while this operation is not applicable to conditions in actual practice any more than the former, it will illustrate a truth. It will show the increase in conductivity resulting from offsetting the tendency of decreased conductivity due to concentration and increased viscosity, by the increased conductivity due to the rise in the temperature level.

TABLE II-*A*

BACKWARD EVAPORATION

Liquor enters 160° F., contains 8.54 per cent solids whose specific heat is 0.5. Temperature spread 220° F. to 100° F. No hydrostatic head. Basis 1,000 lb. solids. (No allowance made for radiation or rise in boiling point.)

	Boiler	1st Effect	2d Effect	3d Effect	4th Effect	5th Effect	6th Effect
Difference of exchange.....	.....	20	20	20	20	20	20
Lbs. steam from	1,766	1,678	1,594	1,520	1,426	1,380	2,100
Per cent solids leaving.....	.....	50.00	27.17	18.96	14.72	12.16	10.42
Heat conducted (Q) B.t.u.....	.....	1,704,000	1,676,320	1,646,880	1,623,760	1,575,160	1,574,680
Temperature level, ° F.....	220	200	180	160	140	120	100
Conductivity K.	.....	382	676	682	603	464	324
Heat conducted ÷20 K. heating surface...	.....	222	125	121	135	170	243
Temp. levels with 167 sq. ft. each.....	[220	192	177	162	146	128	100
Heat conducted ÷heating surface.....	.....	10,190	10,030	9,865	9,725	9,432	9,271

Total heating surface 1,016 sq. ft. Average heating surface 169 sq. ft.

TABLE II-*B*

BACKWARD EVAPORATION

Liquor enters 160° F., contains 8.54 per cent solids whose specific heat is 0.5. Temperature spread 160° F. to 100° F. No hydrostatic head. Basis 1,000 lb. solids. (No allowance made for radiation or rise in boiling point.)

	Boiler	1st Effect	2d Effect	3d Effect	4th Effect	5th Effect	6th Effect
Difference of exchange	.....	10	10	10	10	10	10
Steam from	1,612	1,577	1,563	1,528	1,491	1,457	2,094
Per cent solids leaving	.....	50.00	27.96	19.45	15.00	12.26	10.40
Heat conducted (Q) B.t.u.	.....	1,614,000	1,604,120	1,613,890	1,603,520	1,591,800	1,578,710
Temperature level, ° F.	160	150	140	130	120	110	100
Conductivity (K)	.....	211	473	484	430	364	310
Heat conducted ÷10 K	.....	764	339	333	373	437	509

Total heating surface 2,755 sq. ft.

If Table II-*A* is compared with Table I-*A* it will be found that, owing to the decrease in the viscosity due to increase in temperature with the resulting increase of heat conductivity, the heating surface of 1,638 ft. in Table I-*A* has been reduced to 1,016 sq. ft. in Table II-*A*. Also for the same reason (compare Table II-*B* with Table I-*B*) the square feet of heating surface has been reduced from 4,462 sq. ft. in Table I-*B* to 2,755 sq. ft. in Table II-*B*.

As before mentioned, if steam input only were being considered we should find forward evaporation more economical if the temperature of the liquor is 160° F. If, however, the temperature of the liquor is 100° F. or below, the backward evaporation requires the least input of steam. I submit Tables III and IV, illustrated by Fig. 8, which shows this fact.

A study of Tables III and IV will show that in addition to the economy of steam obtained by backward evaporation, we also require less heating surface; viz., 2,949 instead of 4,429 sq. ft.

From the above it will be seen that the viscosity of liquors so affects the heat conductivity of tubes containing these liquors that it becomes an important factor to be taken into consideration when the solution of an evaporative problem is attempted.

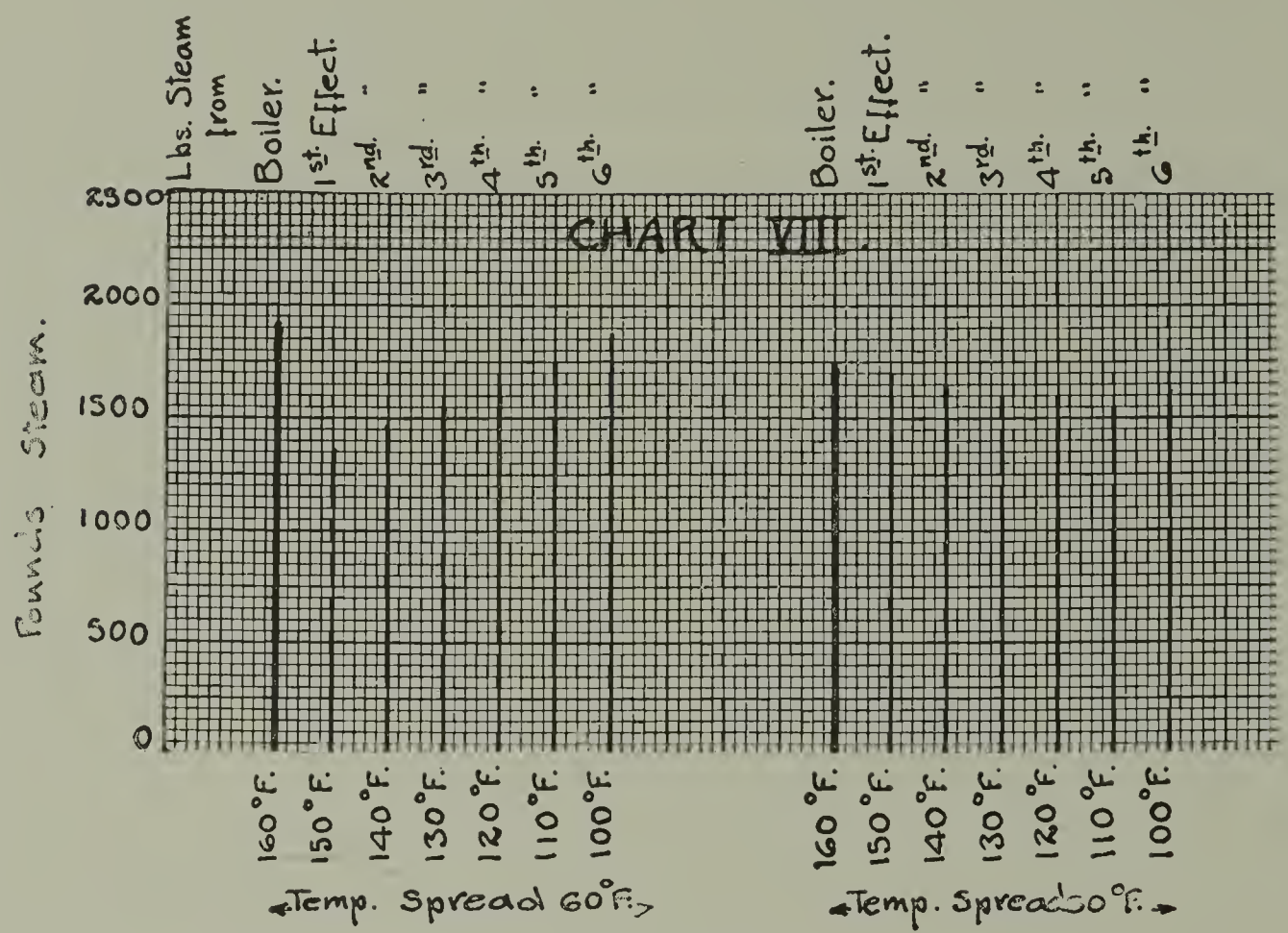


FIG. 8.

TABLE III

FORWARD EVAPORATION

Liquor enters at 100° F., 8.54 per cent solids, specific heat 0.5. Temperature spread 160° to 100° F. No hydrostatic head. Basis 1,000 lb. solids. (No allowance made for radiation or rise in boiling point.)

	Boiler	1st Effect	2d Effect	3d Effect	4th Effect	5th Effect	6th Effect
Difference of exchange.....	10	10	10	10	10	10	10
Lbs. steam from	1,919	1,353	1,462	1,569	1,676	1,775	1,875
Per cent solids leaving.....	.....	9.66	11.24	13.65	17.70	25.80	50.00
Heat conducted B.t.u. (Q)....	.....	1,923,000	1,382,190	1,512,540	1,643,570	1,778,670	1,904,840
Temperature level, ° F.....	.....	150	140	130	120	110	100
Conductivity K.	.....	698	610	526	422	336	70
Heat conducted ÷ 10 K (heating surface)..	.....	276	227	287	389	529	2,721

Total heating surface 4,429 sq. ft.

TABLE IV

BACKWARD EVAPORATION

Liquor enters 100° F., 8.54 per cent solids, specific heat 0.5. Temperature spread 160° to 100° F. No hydrostatic head. Basis 1,000 lb. solids. (No allowance made for radiation or rise in boiling point.)

	Boiler	1st Effect	2d Effect	3d Effect	4th Effect	5th Effect	6th Effect
Difference of exchange.....	10	10	10	10	10	10	10
Lbs. steam from	1,742	1,702	1,662	1,610	1,577	1,542	1,613
Per cent solids leaving.....	.....	50.00	27.02	18.64	14.33	11.69	9.91
Heat conducted B.t.u. (Q)....	.....	1,744,482	1,732,456	1,716,280	1,693,320	1,680,880	1,668,170
Temperature level, ° F.....	.....	150	140	130	120	110	100
Conductivity (K).....	.....	212	482	492	432	358	300
Heat conducted 10 K.....	.....	823	359	349	392	470	556

Total heating surface 2,949 sq. ft.

(10) *Sequence of Evaporation.*—In the above I have shown some all-important reasons for altering the sequence of evaporation. Aside from this, however, I may add that there are some liquors which are so nearly solid in a 50 per cent solution at 100° F. that it becomes absolutely impossible to run the liquor forward in the usual manner and take the liquor out at 100° F. If forward evaporation is attempted with such liquors the temperature in the last effect must be raised considerably and the heating surface either increased enormously or the difference of exchange increased enormously, or both. Any and all of these remedies make for inefficiency, as has already been shown. Changing the sequence of evaporation will enable one oftentimes to get over this difficulty. Some processes call for a liquor much hotter than would naturally come from the vacuum effect and then this liquor must either be heated after leaving the evaporator, or the sequence of evaporation must be changed to meet the conditions. There are also conditions in which another process is inserted into part of the evaporative process, and this may also call for a change in sequence of evaporation.

The effects of the other variables are so well understood that it is unnecessary to give a discussion of great length relative to the same.

(11) *Elimination of Condensation.*—Inasmuch as the steam in transferring its heat necessarily condenses to water, an efficient means of removing this condensation must be provided, for otherwise the condensation would fill the evaporator, thereby covering up the heating surfaces and the evaporator would cease to function. This condensation should, however, be removed in such a manner as to prevent the simultaneous removal of any steam.

(12) *Elimination of Entrained Air.*—Inasmuch as all steam contains entrained air or other non-condensible gases, it will be readily seen that the condensation of the steam and its subsequent removal will leave the air or other non-condensible gases in the steam space and if these are not removed they will gradually accumulate in the steam space, thereby giving the effect of reducing the heating surface. Thus, if you have a mixture of 50 per cent air and 50 per cent steam you may roughly consider that 50 per cent of your heating surface is in contact with air and only the other 50 per cent in contact with the steam.

(13) *Elimination of Steam from Liquor so as to Avoid Foaming.*—Many liquors tend to foam; some of these tend to foam more or less through the entire process of evaporation, while others tend to foam only at certain stages. The construction of the evaporator must be such as to provide for this separation of foam, for lack of such may not only tend to make the evaporator inefficient, but it may cause serious losses. Furthermore, the drip or condensate may be spoiled for uses to which it could otherwise be put but for the presence of the liquor carried over in the foam.

(14) *Keeping Conducting Surfaces Wet.*—In attempts to eliminate foam it often happens that some surfaces are not covered at all times with the liquor. If these periods are of too long a duration it may happen that the residues of liquor may deposit and bake thereon and thus change to a substance which will not redissolve when the liquor finally comes in contact therewith. This has the effect of reducing the heating surface and consequently the capacity of the evaporator.

(15) *Keeping Surfaces Free from Incrusting Matter.*—Many liquids contain substances which under influence of heat may deposit on the tubes, even though the tubes may be kept wet and as these incrusting matters are usually non-conductors of heat, the efficiency of the evaporator may be greatly impaired. As an example of such

incrusting matter calcium sulphate may be mentioned. If these substances are liable to be present then their presence must be taken into consideration and the evaporator so constructed as to provide for their easy removal.

(16) *Mechanical Construction.*—In carrying out the above principles it must be borne in mind that whatever is done the mechanical construction must be such as to avoid undue stresses and strains which would otherwise cause leakage of air or liquor. Also, the mechanical construction should be such as to reduce the convection surfaces to a minimum so as not to lose too large a percentage of heat by so-called radiation.

(17) *Number of Effects.*—No definite rules can be applied to this subject. The number of effects used will depend primarily upon the cost of fuel and the amount of liquor to be evaporated. Generally speaking, the number of effects may be greater if the amount of liquor to be evaporated is great and the price of fuel is high, but in each case the addition of another effect must be considered from the standpoint of cost of operation and fixed charges and unless the saving of fuel is such as more than to pay for maintenance and fixed charges, together with a generous amortization charge, there is no object in adding such an effect. Generally speaking, a larger number of effects can be used by using counter-current or backward evaporation than can be used in forward evaporation. As before stated, evaporators are not built for a uniform difference of exchange between the different effects, so the heating surfaces and temperature levels as given are not correct. Nevertheless, the assumption of some difference of exchange facilitates the making of calculations and from these calculations you can get the amount of heat conducted through the tubes of each evaporator.

Heat Conducted According to Temperature Differences.—If you will refer to Tables I-*A* and I-*B* you will observe that if you compare the heat conducted in an effect of Table I-*A* with that conducted in the corresponding effect of Table I-*B* there is a variance in amounts. Table I-*A* has a temperature spread 100 per cent greater than Table I-*B* and thus requires more initial steam for the same amount of evaporation, and the effect of this steam is to increase the total amount of heat conducted.

Now if you compare Tables II-*A* and II-*B* you will find that the same 100 per cent difference in temperature spread in backward

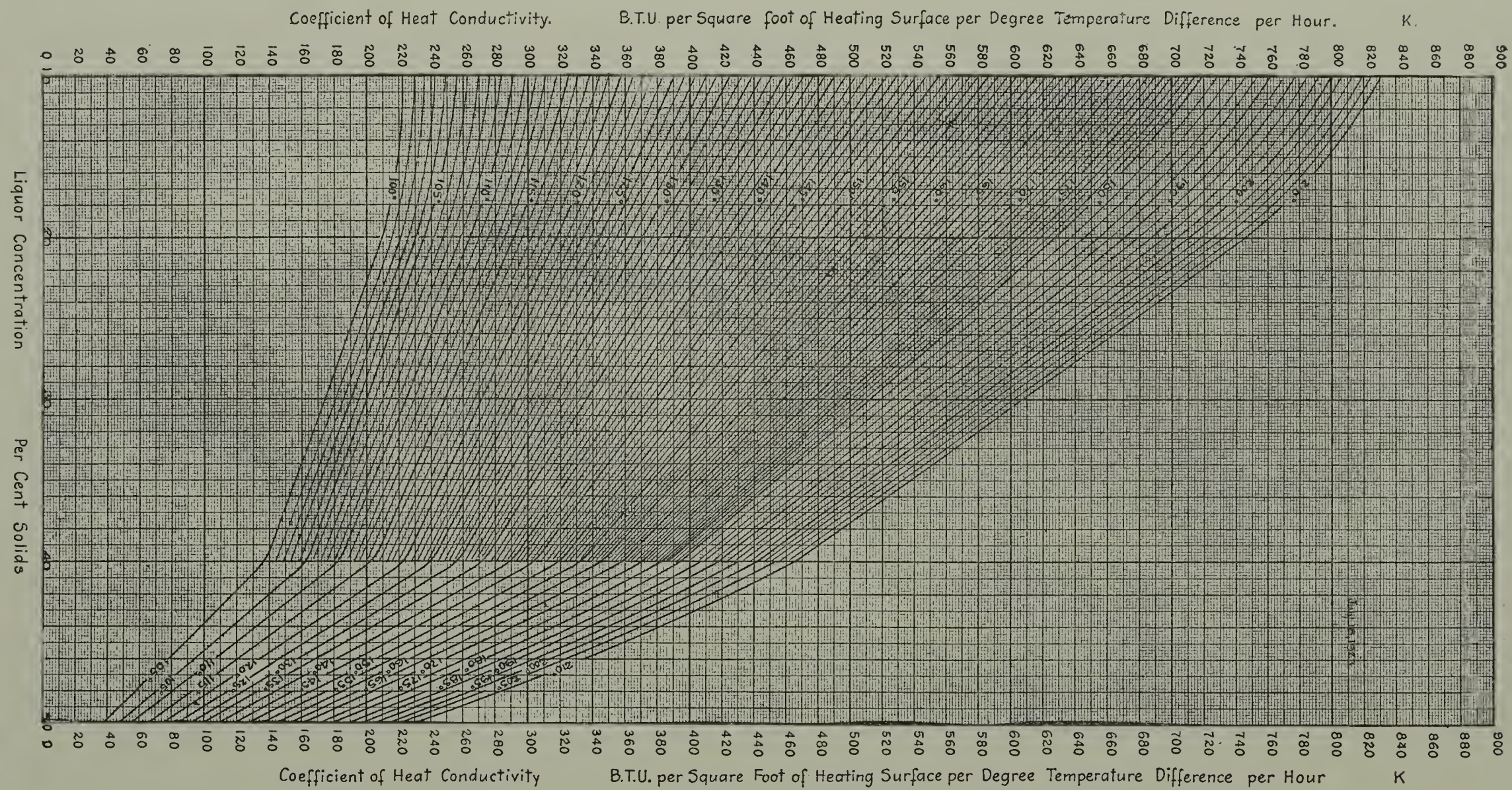


FIG. 9. Evaporation of Waste Sulphite Liquor in Horizontal-Tube Evaporator. Coefficients of Heat Conductivity from Steam to Boiling Waste Sulphite Liquors. No Hydrostatic Head on Liquor. Temperature Levels from 100° F. to 210° F. Temperature Difference between Steam and Boiling Liquor 5° F. Liquor Concentrations from 10 Per Cent to 50 Per Cent Solids.

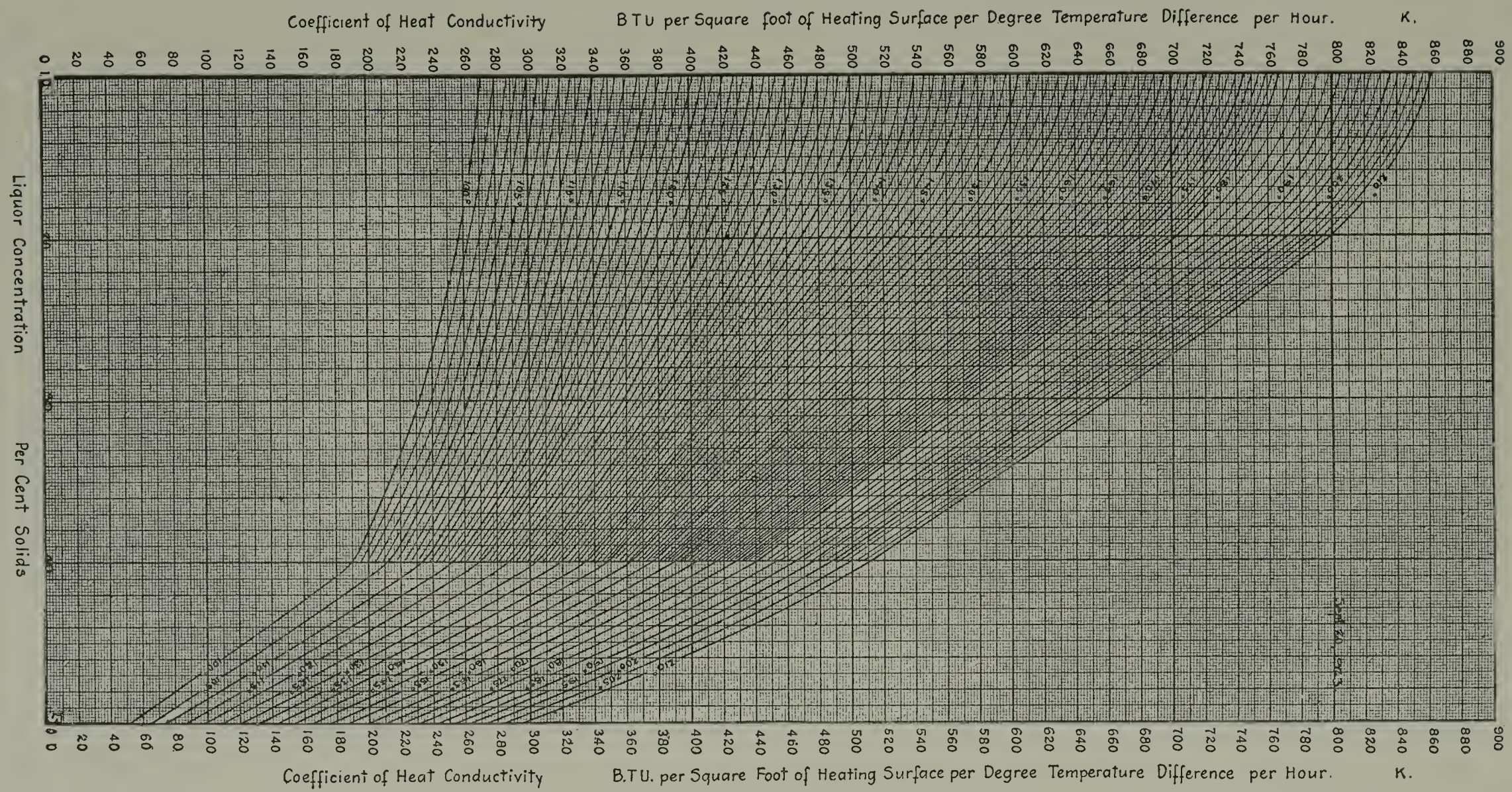


FIG. 10. Evaporation of Waste Sulphite Liquor in Horizontal-Tube Evaporator. Coefficients of Heat Conductivity from Steam to Boiling Waste Sulphite Liquors. No Hydrostatic Head on Liquor. Temperature Levels from 100° F. to 210° F. Temperature Difference between Steam and Boiling Liquor 7° F. Liquor Concentrations from 10 Per Cent to 50 Per Cent.

evaporation makes, on the average, very little difference in the heat conducted, though the effect of the greater amount of steam is still visible. In either case the variations in the total heat conducted in all the effects does not vary much over 2 per cent, an amount which is negligible. If, now, the total heat conducted through the tubes in each effect is divided by the product of the heat conductivity at the required percentage of solids at the corresponding temperature level, and the temperature difference, we get the square feet of heating surface. In order to get the heat conductivity I submit Figs. 9 to 14, inclusive. These figures show the heat conductivity using 5, 7, 10, 15, 20, and 25° difference of exchange for sulphite liquor at varying temperature levels and varying percentages of solids. For example, let us take Table II-*A* and we find 50 per cent liquor in No. 1 effect boils at a 200° F. temperature level, with a temperature difference of 20° F. By referring to Fig. 13 we find 50 per cent liquor at 200° F. temperature level has a heat conductivity of 382. Then $1{,}704{,}000 \div 20 \times 382 = 222$, the square feet of heating surface in No. 1 effect. In like manner the heating surfaces in the other effects are determined. If we add all these heating surfaces together we find we have a total heating surface of 1,016 sq. ft. or an average of about 167 square feet each. It often happens that a mill is contemplating the evaporation of certain liquids and has space to put up only a certain-sized evaporator and it is desired to know if steam available at certain pressures can be used for this purpose. In this case the heating surface is known but the temperature levels and the differences of exchange are not known.

Suppose in Table II-*A* we know the heating surface could be only 169 sq. ft. for each of the six evaporators. We would then make the calculation as usual and having determined the total heat conducted through the tubes in each effect we could divide the same by the heating surface and get a product of the heat conductivity and the difference of exchange. Now we know the temperature level of No. 6 effect to be 100°. If then we look up 9270 on the 10 per cent solid line on product chart, Fig. 15, we find the difference of exchange is 28° F. If we make no allowance for the rise in boiling point, then the temperature of the boiling liquor in effect No. 5 is $100 + 28$ or 128°. If the boiling point increased at this concentration you would add the increase to the 128°. If you now look up at 12 per cent solids 9432 on the 128° temperature level chart you would get

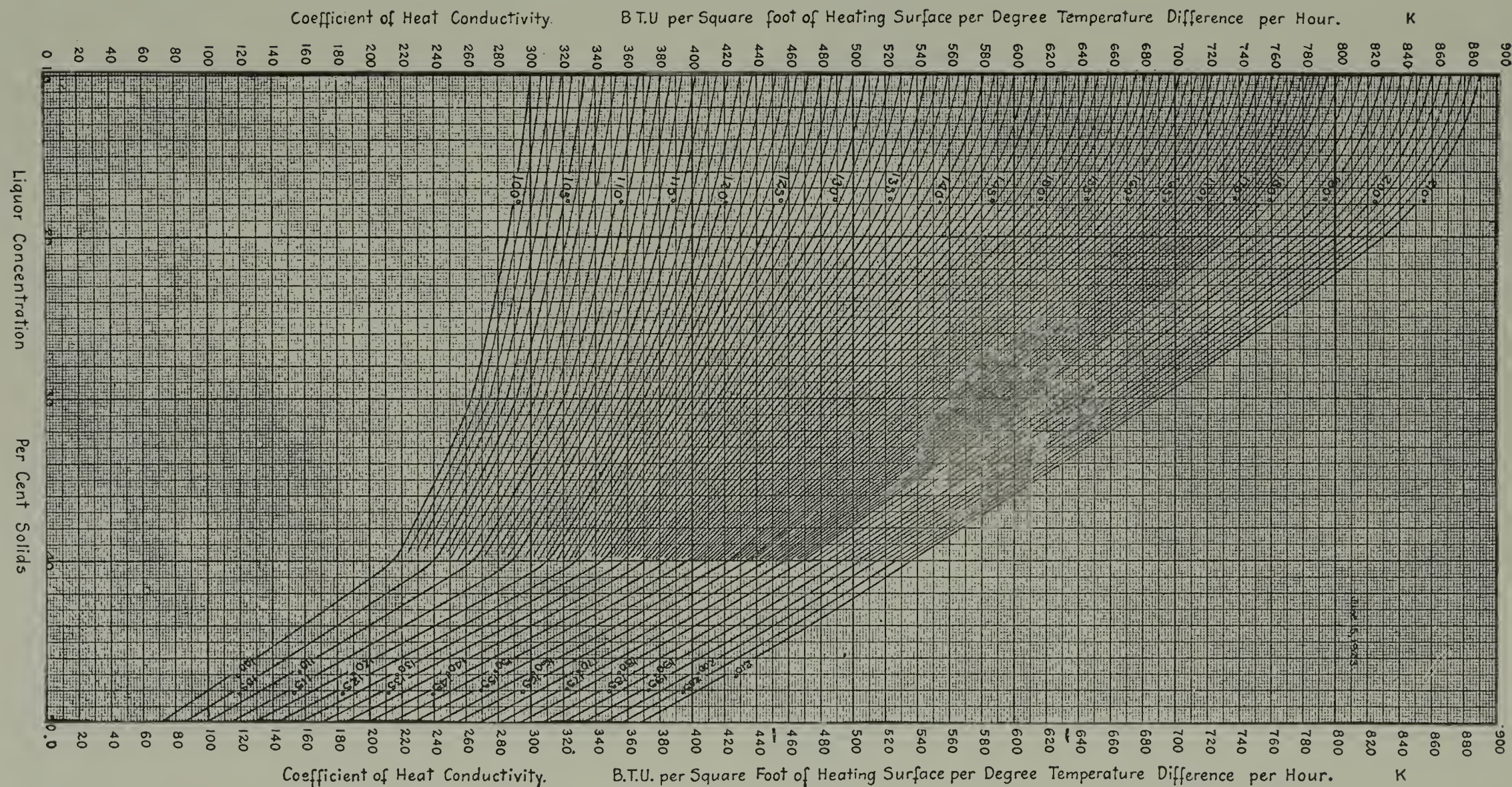


FIG. 11. Evaporation of Waste Sulphite Liquor in Horizontal-Tube Evaporator. Coefficients of Heat Conductivity from Steam to Boiling Waste Sulphite Liquors. No Hydrostatic Head on Liquor. Temperature Levels from 100° F. to 210° F. Temperature Difference between Steam and Boiling Liquor 10° F. Liquor Concentrations from 10 Per Cent to 50 Per Cent Solids.

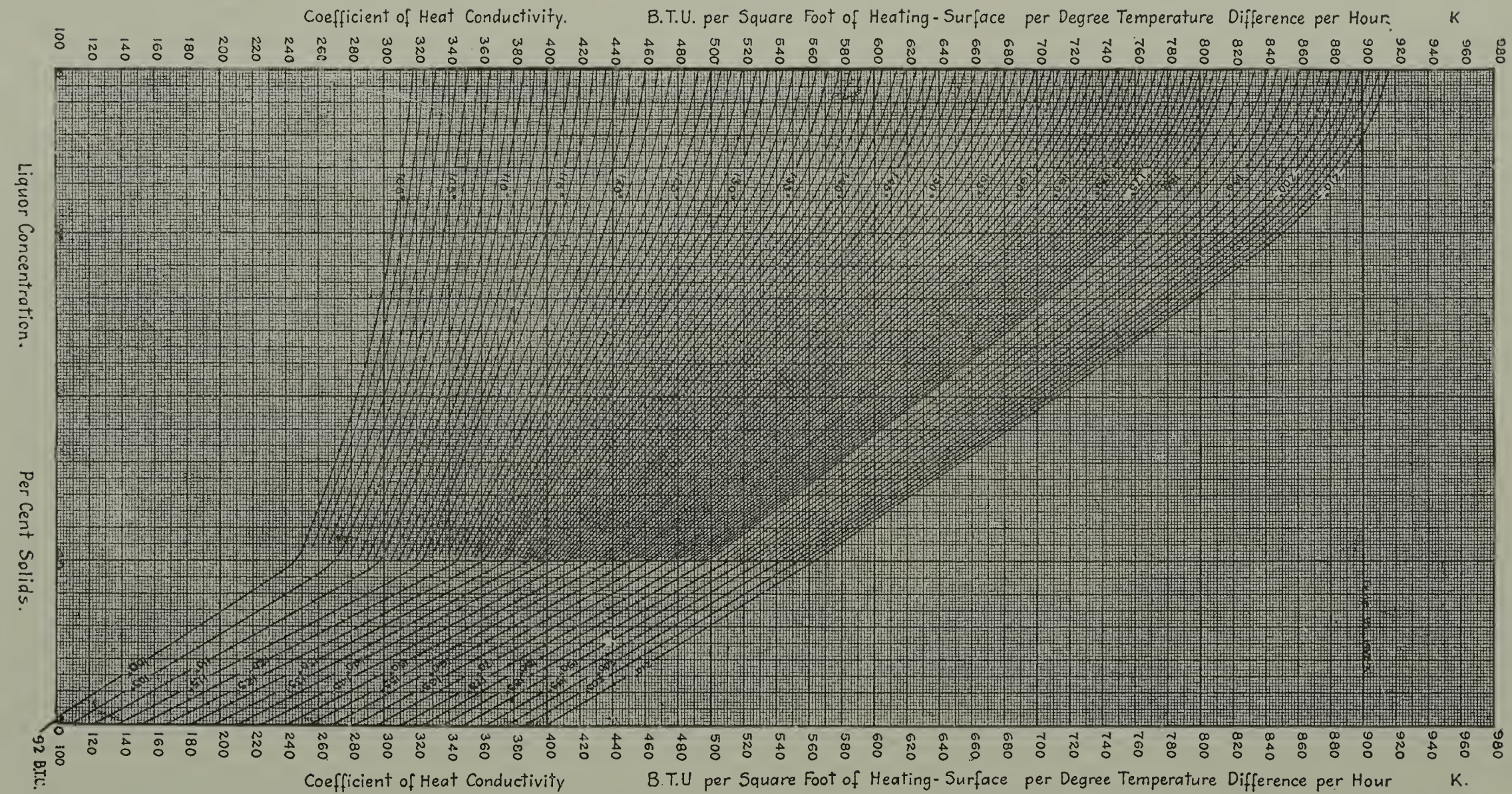


FIG. 12. Evaporation of Waste Sulphite Liquor in Horizontal-Tube Evaporator. Coefficients of Heat Conductivity from Steam to Boiling Waste Sulphite Liquors. No Hydrostatic Head on Liquor. Temperature Levels from 100° F. to 210° F. Temperature Difference between Steam and Boiling Liquor 15° F. Liquor Concentrations from 10 Per Cent to 50 Per Cent Solids.

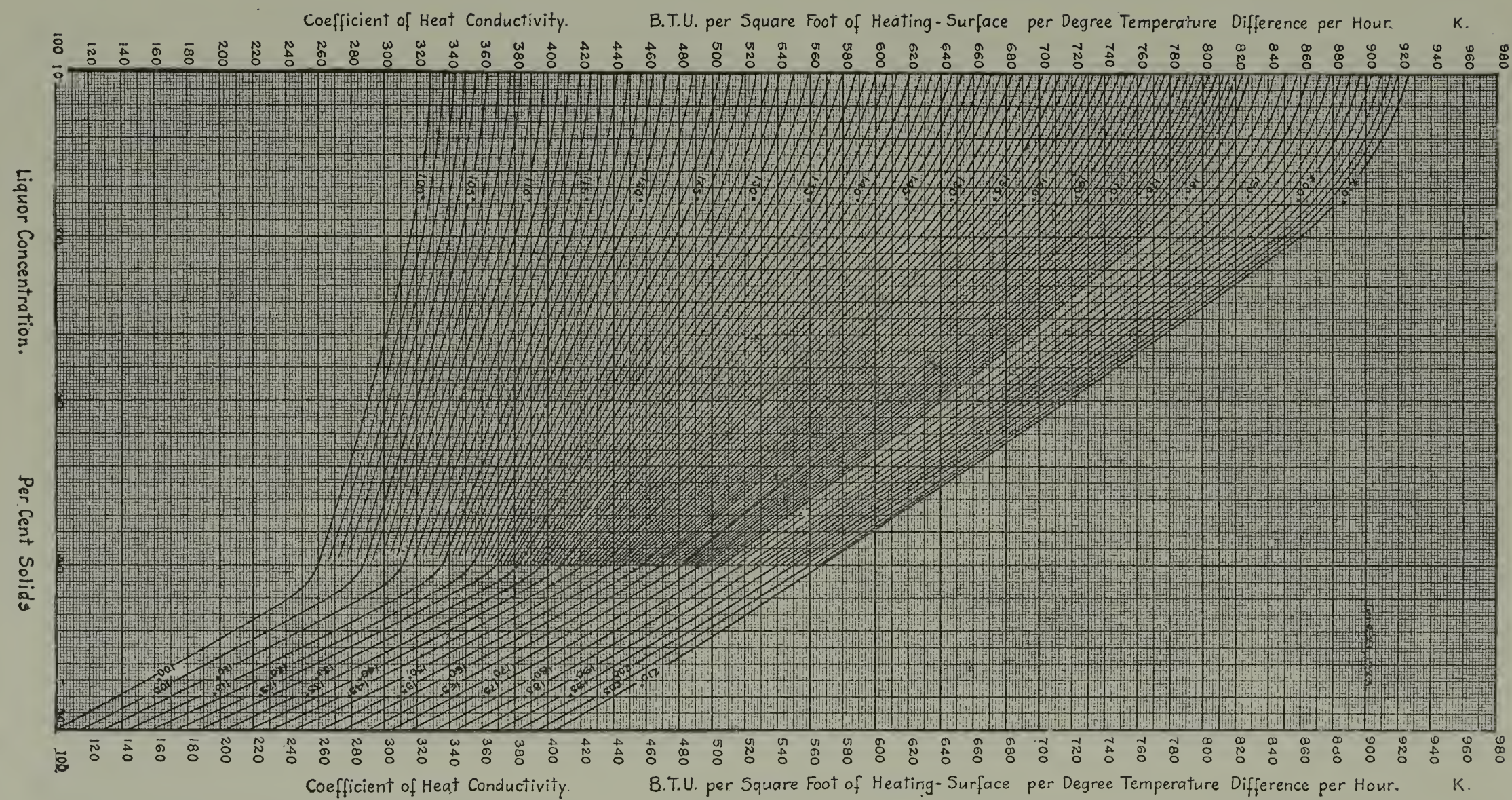


FIG. 13. Evaporation of Waste Liquor in Horizontal-Tube Evaporator. Coefficients of Heat Conductivity from Steam to Boiling Waste Sulphite Liquors. No Hydrostatic Head on Liquor. Temperature Levels from 100° F. to 210° F. Temperature Difference between Steam and Boiling Liquor 20° F. Liquor Concentrations from 10 Per Cent to 50 Per Cent Solids.

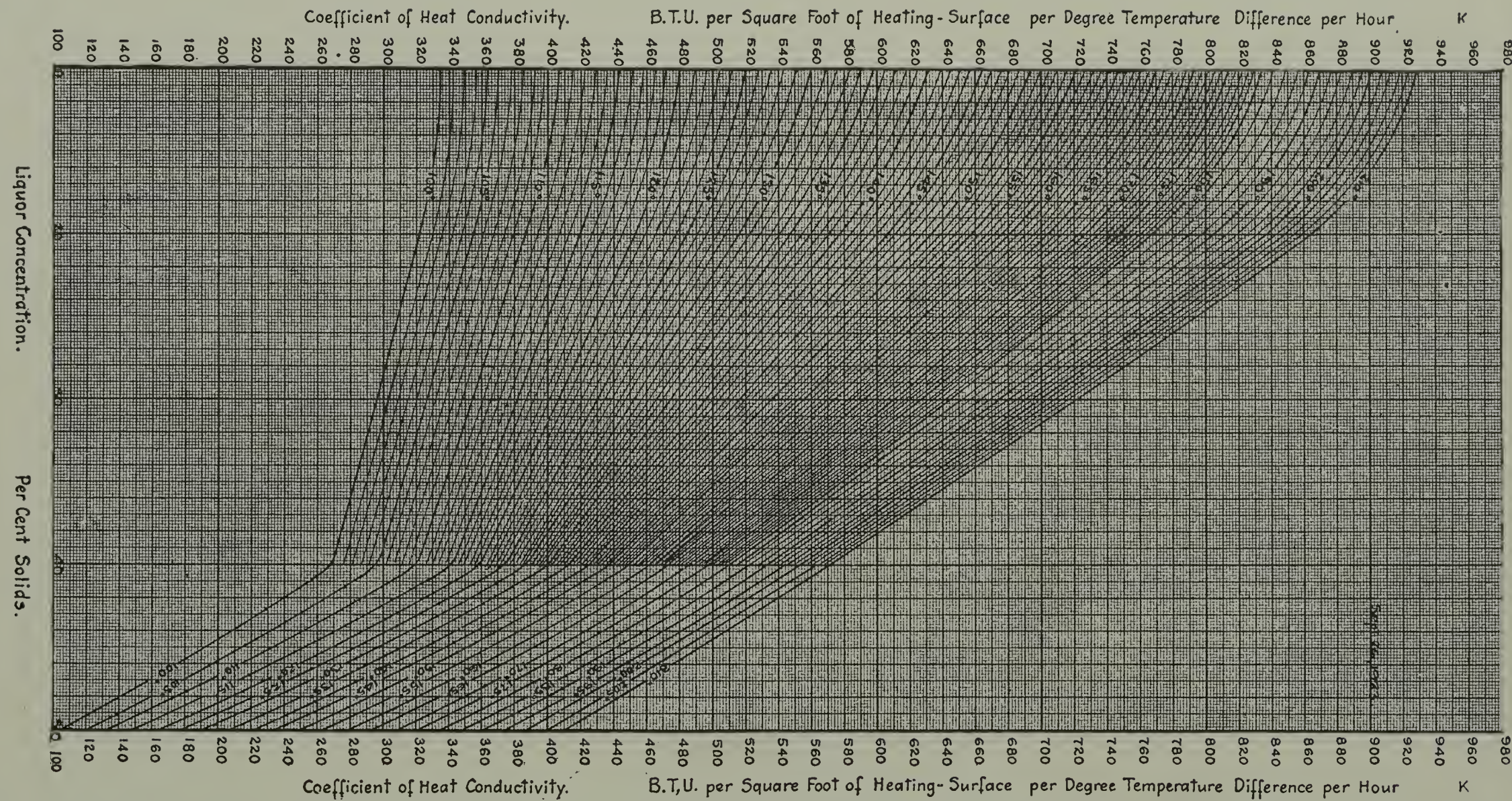


FIG. 14. Evaporation of Waste Sulphite Liquor in Horizontal-Tube Evaporator. Coefficients of Heat Conductivity from Steam to Boiling Waste Sulphite Liquors. No Hydrostatic Head on Liquor. Temperature Levels from 100° F. to 210° F. Temperature Difference between Steam and Boiling Liquor 25° F.

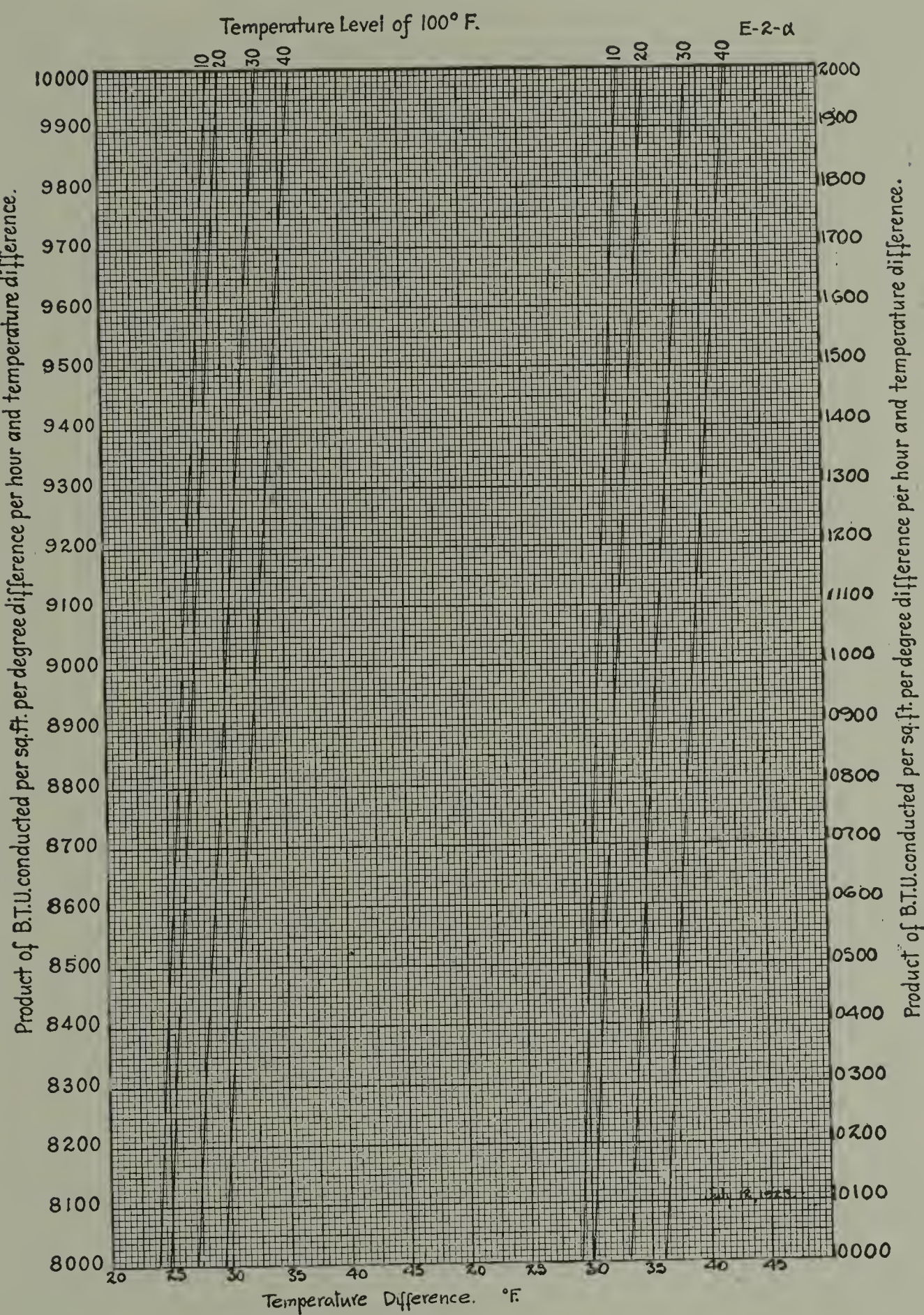

Temperature Level of 100° F.
E-2-α
10 20 30 40
10 20 30 40
10000
9900
9800
9700
9600
9500
9400
9300
9200
9100
9000
8900
8800
8700
8600
8500
8400
8300
8200
8100
8000
Product of B.T.U. conducted per sq. ft. per degree difference per hour and temperature difference.
12000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
0900
0800
0700
0600
0500
0400
0300
0200
0100
0000
Product of B.T.U. conducted per sq. ft. per degree difference per hour and temperature difference.
20 25 30 35 40 45 20 25 30 35 40 45
Temperature Difference. °F.

FIG. 15.

18° difference of exchange. (Note: I have considerably over 100 of these charts and only submit one, namely, Fig. 15, to illustrate the type of chart employed.) By this method you can get a fair idea of the temperature spread and temperature levels. In this particular case the total temperature spread happens by coincidence to be the same as that already assumed. This is not usually true, however, for in most cases, even with the heating surfaces obtained by averaging as above, the temperature spread would be less than that assumed. If the heating surface had been greater the total temperature spread would have been less and vice versa. If the jump of heating surface in the last effect was great in Table I-*A*, then the total temperature spread based on the average heating surface would be less. In this table the average heating surface is 273. This reduction in temperature level is due to the fact that with a small heating surface at a low temperature level the difference of exchange must necessarily be great and if this is true then you have raised the preceding temperature levels and the increase in conductivity due to this cause usually more than offsets the first high temperature difference.

In Table I-*A* I have shown the total temperature spread by this method is only 106° instead of 120°, yet the temperature difference in No. 6 effect is 68° instead of 20 degrees, as assumed when the table was calculated. These tables must be taken in an illustrative sense only, for no sane person would think of putting in a six effect system for the small amounts shown. The small amounts shown were purposely taken in order that the tables might be within the limits of a page. For larger capacities these figures can be multiplied by the proper factor. These tables are based on figures experimentally obtained on clean tubes. If these figures are used proper allowance must be made for the several factors which enter into a commercial operation.

It now remains for us to show the type of evaporator proposed, which will take into consideration the above fundamental principles. The curves are based on data obtained on an iron tube 3″ in diameter and 25′ 0″ long, enclosed in a steam jacket and very slightly inclined from the horizontal. It will thus be seen that the static head is limited to the liquor over the tube, which probably does not exceed one-eighth of an inch on the bottom of the tube and is nothing at the top of the tube. The liquor is fed into the tube.

Now, while the question of distribution of liquor in one tube without any static head is a simple matter, the question of the same distribution in a multiplicity of tubes nested together as in a boiler is not so simple. Means must be provided to accomplish this result or the project will become a failure, for it must be remembered that these constants given above do not hold true for any conditions except for those under which they were determined.

The method proposed was to spray the liquor by means of a pump against the tube sheet spaced off horizontally by gill flanges or troughs so that the liquor striking between the tubes would be collected and pass through the tubes in its particular zone and not run down the tube sheet. The second step was to obtain a nozzle which distributed evenly and yet one which would not plug from even large-sized impurities. Having some doubt about the nozzles we conducted the experiments with them first. We found one nozzle which sprayed evenly. This was made by the Spray Engineering Company. The other nozzles tried gave hollow cones or small angles of discharge. The first step was to determine the angle of horizontal discharge, for this must be known in order to get the distance of the nozzle from the tube sheet. The vertical angle will vary according to the distance of the nozzle from the tube sheet, owing to the effect of gravity on the water during its travel. This factor, however, did not worry us, as we could take care of this by lengthening our gill flanges.

A discussion of the various tests to which spray nozzles were put and the conclusions drawn from the same, would make a small volume in itself, so I will slide over this part of the paper, giving in brief only a few of the results applicable to this subject.

Each of the three nozzles projects practically a solid spray. At the higher pressures the spray carries farther, although the distance, for each nozzle separately, at which the spray is seven feet wide (shown on charts), does not vary to any appreciable extent with the pressure. The same holds true for a spray twelve feet in width.

In the charts, "Distance in Feet" represents distance along the floor directly in front of the nozzle. The height of the spray at a width of twelve feet could not be measured for every pressure, owing to the fact that the lower portion of the stream struck the floor inside the proper point. Curves on the charts indicate which were thus affected. Neither could the nozzle be raised further, as then the upper portion of the stream would strike the ceiling. This testing was done indoors, to avoid error caused by wind.

The points on the outside of the sprays where measurements were made were taken where an appreciable number of drops fell. Consequently, some liquid will fall outside of the measured area, but probably not much.

The distance at which the spray is seven and twelve feet wide was found by sighting along the two sides of the spray from the nozzles, lining off the path of the spray on the floor, and then measuring the distance sought.

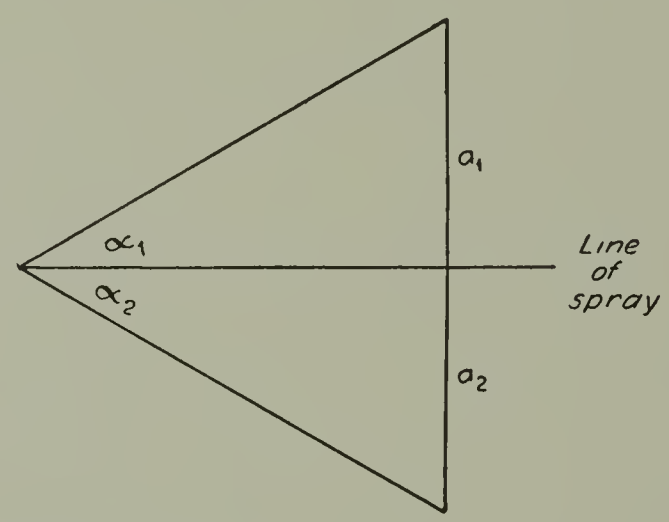
All measurements were made with water flowing through the same supply line for all three nozzles. Nozzles 10 *BA* and 10 *B* fit the same size pipe; nozzle 11 *A* taking a larger pipe. Connection in the case of the latter was made by means of a bushing.

Angles of Sprays

Angles of sprays were calculated as follows:

$$\frac{a_1}{c} = \text{tangent}$$

$$\frac{a_2}{c} = \text{tangent}$$



$$\alpha_1 + \alpha_2 = \text{angle of spray}$$

Nozzle No. 10 BA

5 lbs. pressure

$a_1 = 0.875$

$0.875 = \text{tangent } \alpha_1 = 41°12'$

$a_2 = 0.775$

$0.775 = \text{tangent } \alpha_2 = 37°48'$

$c = 1.0$

$79°$

Angle of spray $= 79°$

30 lbs. pressure

$a_1 = 0.975$ $\quad 0.975 = \text{tangent } \alpha_1 = 44°18'$

$a_2 = 0.675$ $\quad 0.675 = \text{tangent } \alpha_2 = 34°\ 6'$

$78°24'$

Angle of spray $= 78° 30'$ (taken as $80°$)

From the angle of spray between 5 lbs. up to 30 lbs. pressure, the conclusion was drawn that the angle of spray does not vary to any great extent with increase in pressure.

Nozzle No. 10 B

5 lbs. pressure

$a_1 = 0.975$ $\quad$ $0.975 = \text{tangent } \alpha_1 = 44°18'$

$a_2 = 1.195$ $\quad$ $1.195 = \text{tangent } \alpha_2 = 50°$

$94°18'$

Angle of spray $= 94°18'$

30 lbs. pressure

$a_1 = 1.125$ $\quad$ $1.125 = \text{tangent } \alpha_1 = 48°24'$

$a_2 = 1.025$ $\quad$ $1.025 = \text{tangent } \alpha_2 = 45°42'$

$94°06'$

$c = 1.0$ $\quad$ Angle of spray $= 94°06'$

Nozzle No. 11 A

5 lbs. pressure

$a_1 = 1.025$ $\quad$ $1.025 = \text{tangent } \alpha_1 = 45°42'$

$a_2 = 1.825$ $\quad$ $1.825 = \text{tangent } \alpha_2 = 61°18'$

$107°$

$c = 1.0$ $\quad$ Angle of spray $= 107°$

30 lbs. pressure

$a_1 = 1.255$ $\quad$ $1.255 = \text{tangent } \alpha_1 = 51°24'$

$a_2 = 1.525$ $\quad$ $1.525 = \text{tangent } \alpha_2 = 56°42'$

$c = 1.0$ $\quad$ $108°06'$

Angle of spray $= 108°$

Height of Spray when Width is Seven Feet

Nozzle No. 10 BA

Lbs. Pressure	5	10	15	20	25	30	
Top	11.35	12.30	12.50	12.85	13.00	13.10	
Bottom	4.30	4.75	5.15	5.40	5.65	5.80	
Height of spray, feet	7.05	7.55	7.35	7.45	7.35	7.40	7.35 ft.-mean
Diff. from mean height	−0.31	+0.19	−0.01	+0.09	−0.01	+0.04	

Distance from nozzle = 4.5 feet

Nozzle No. 10 B

Lbs. Pressure	5	10	15	20	25	30	
Top	12.00	12.63	12.85	12.95	13.05	13.18	
Bottom	4.23	4.35	4.50	4.70	4.85	4.95	
Height of spray, feet	7.77	8.28	8.35	8.25	8.20	8.23	8.18 ft.-mean
Diff. from mean height	−0.41	+0.1	+0.17	+0.07	+0.02	+0.05	

Distance from nozzle = 3.66 feet

Nozzle No. 11 A

Lbs. Pressure	5	10	15	20	25	30	
Top	11.65	12.30	12.48	12.62	12.75	12.83	
Bottom	4.10	4.35	4.50	4.70	4.85	5.00	
Height of spray, feet	7.55	7.95	7.98	7.92	7.90	7.83	7.85 ft.-mean
Diff. from mean height	−0.3	+0.1	+0.13	+0.07	+0.05	−0.02	

Distance from nozzle = 2.87 feet

Height of Spray when Width is Twelve Feet

Nozzle No. 10 BA

Lbs. Pressure	5	10	15	20	25	30	
Top			13.70	14.05	14.28	14.38	
Bottom			.65	1.3	1.8	2.15	
Height of spray, feet			13.05	12.75	12.48	12.23	12.63 ft.-mean
Diff. from mean height			+0.42	+0.12	−0.15	−0.40	

Distance from nozzle = 7.6 feet

Nozzle No. 10 B

Lbs. Pressure	5	10	15	20	25	30	
Top				14.4	14.6	14.75	
Bottom				.1	.3	.5	
Height of spray, feet			14.3	14.3	14.3	14.25	14.28 ft.-mean
Diff. from mean height			+0.02	+0.02	+0.02	−0.03	

Distance from nozzle = 6.25 feet

Nozzle No. 11 A

Lbs. Pressure	5	10	15	20	25	30	
Top	12.0	13.6	13.8	14.0	14.0	14.2	
Bottom	0.0	.9	1.3	1.6	1.8	2.0	
Height of spray, feet	12.0	12.7	12.5	12.4	12.3	12.2	12.35 ft.-mean
Diff. from mean height	−0.35	+0.45	+0.25	+0.15	+0.05	−0.15	

Distance from nozzle = 4.75 feet

I also submit Figs. 16, 17, and 18, illustrating the above. As the other makes of nozzles were rejected for this purpose it is unnecessary to encumber this paper with the data thereon, though they are exceedingly interesting.

I also submit Table V, illustrated by Fig. 19, which shows the distances from the nozzle tip in which the spray covers the widths of 7 and 12 feet, respectively.

Having determined the above we are now in a position to determine the evenness of the distribution over the tube sheet. A tube sheet with tubes expanded therein, was made as illustrated by Fig. 20. It will be seen that the tubes are of such lengths that pails can be hung thereon and actual measurements made of the water flowing through each of the tubes. Fig. 21 shows a sketch of the tube sheet in which the horizontal rows are designated by letters and the vertical rows by numbers.

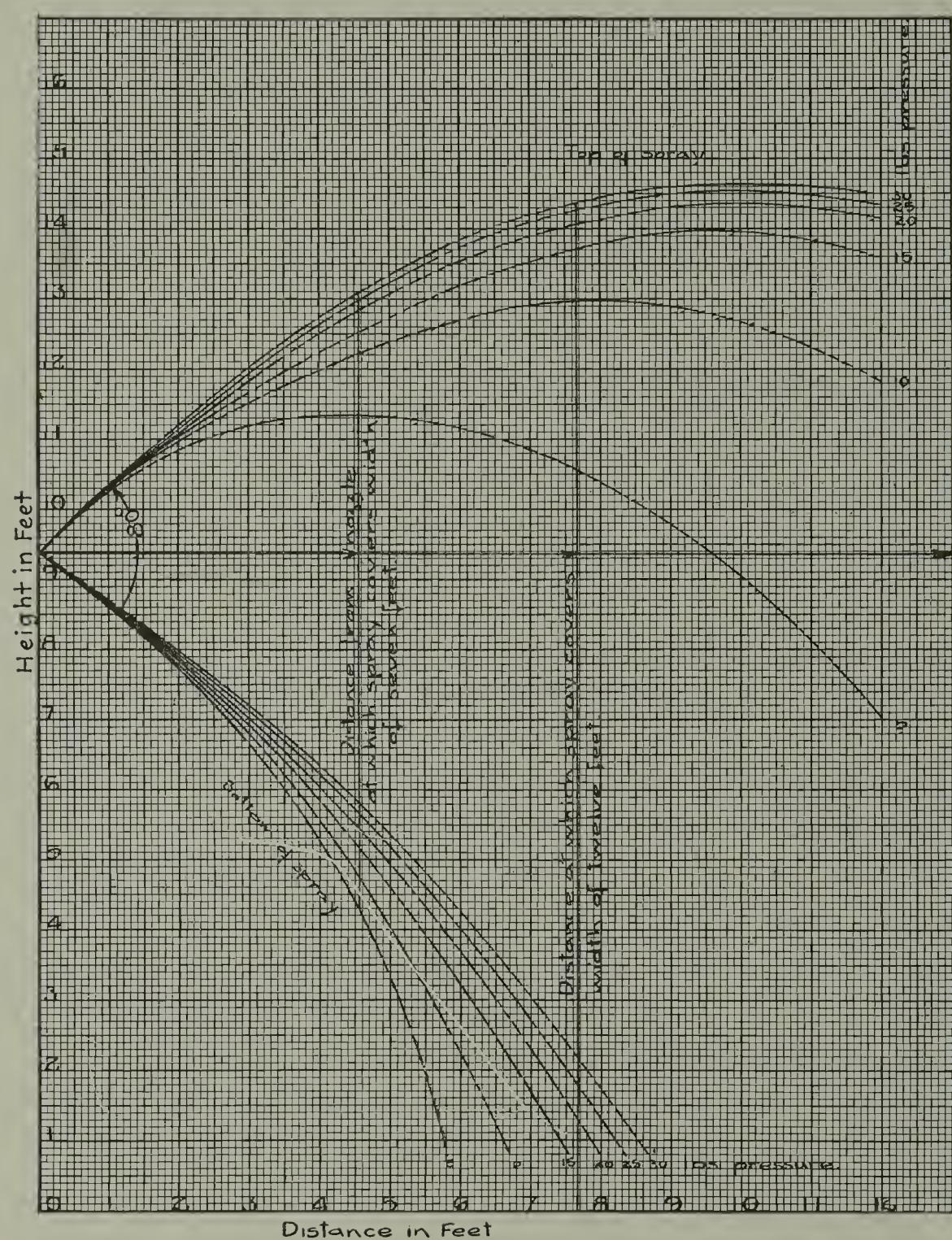


FIG. 16. Spray Engineering Co. Nozzle No. BA. 9/16-inch orifice. Nozzle axis horizontal.

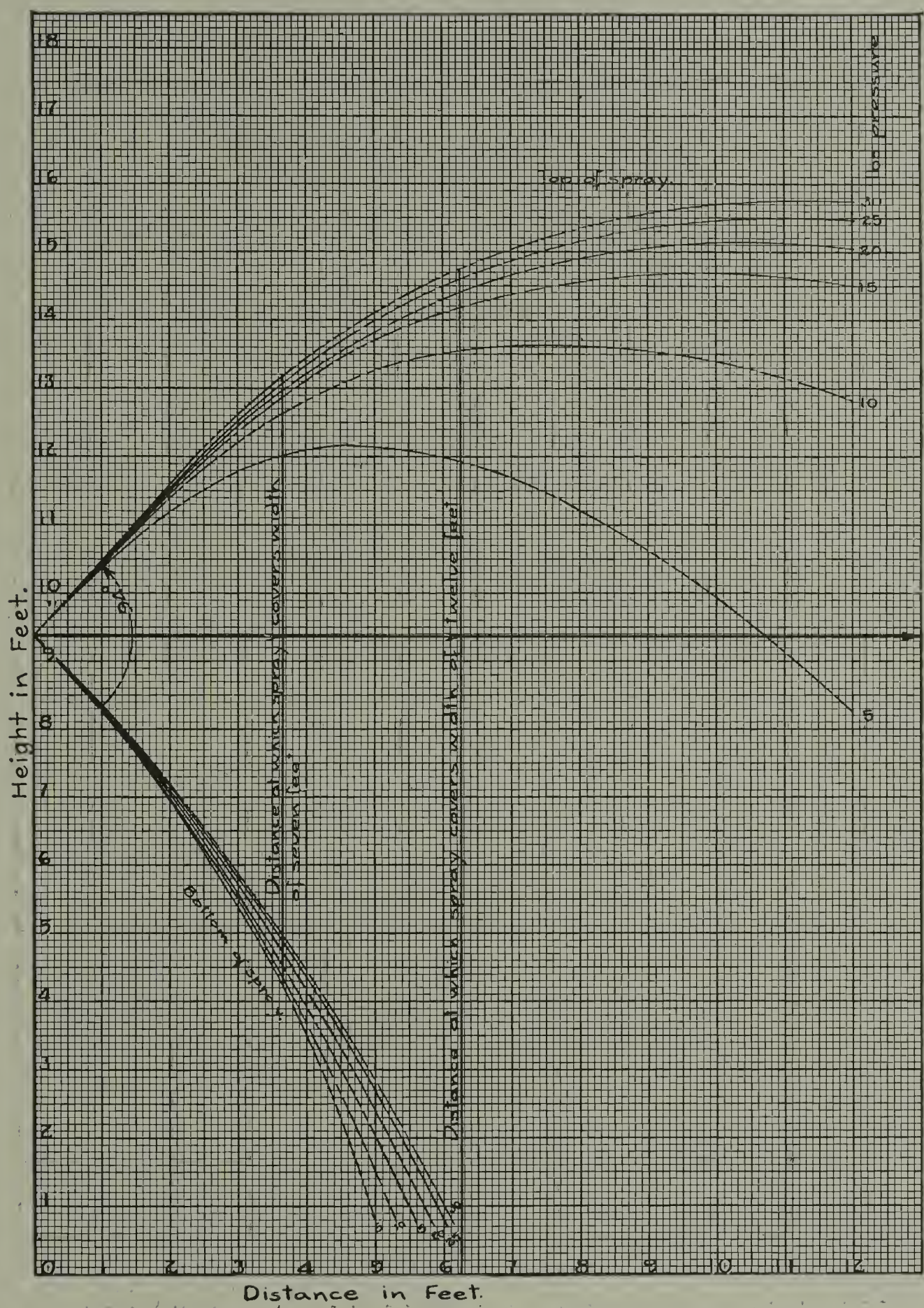


FIG. 17. Spray Engineering Co. Nozzle No. 10 B. ⅝-inch orifice.

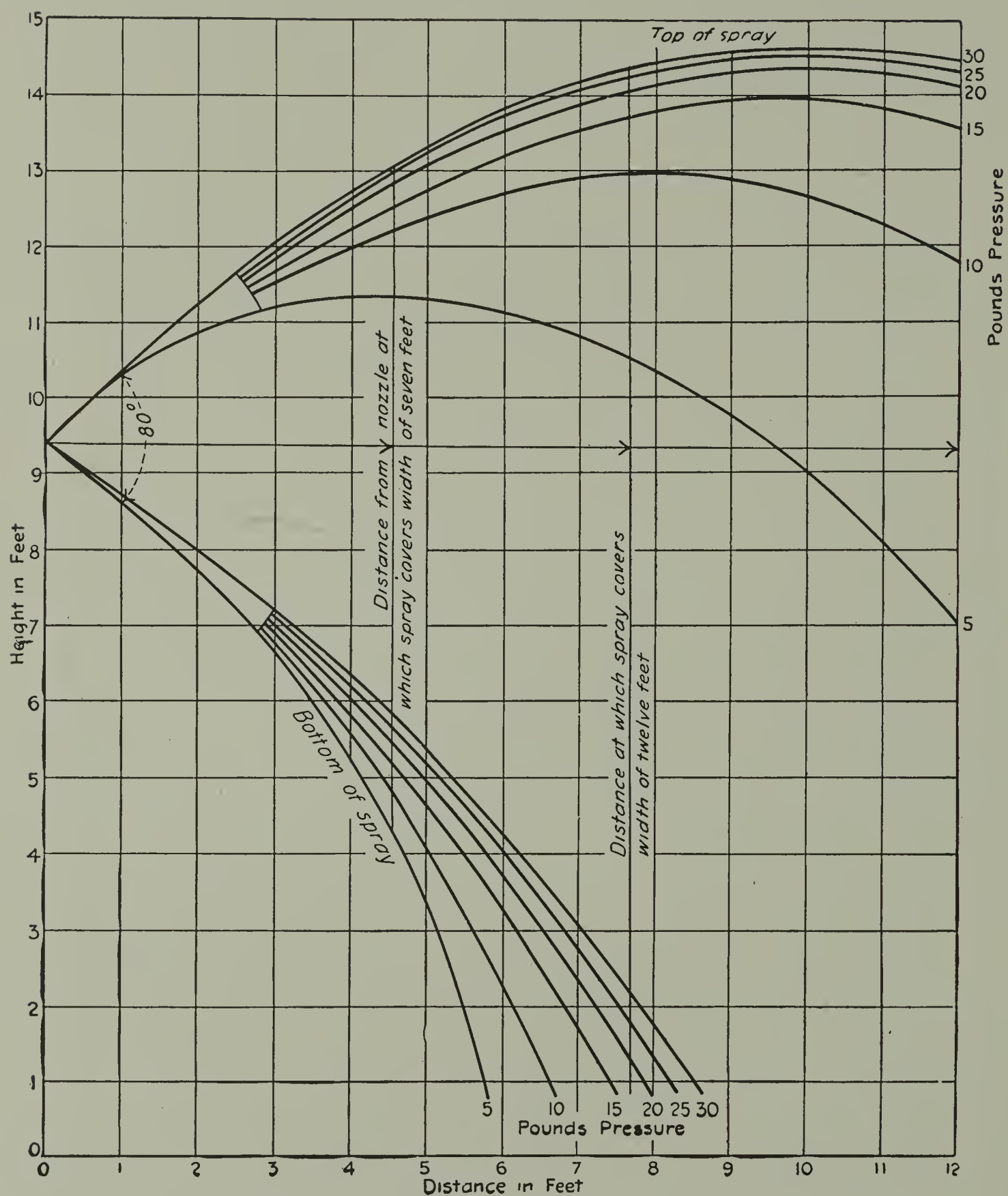


FIG. 18. Spray Engineering Co. Nozzle No. 11 A. ¾-inch orifice.

TABLE V

COMPARISON OF THE THREE TYPES OF SPRAY-NOZZLES

Distance from nozzle-tip to point where spray is

Nozzle No.	Supply Pipe	Diameter Orifice	7 feet in width.			12 feet in width.		
			Spraco	Type B	Type C	Spraco	Type B	Type C
10 *BA*	$1\frac{1}{2}$-inch	$\frac{9}{16}$-inch	4.5 feet			7.60 feet		
10 *B*	$1\frac{1}{2}$-inch	$\frac{5}{8}$-inch	3.66 "			6.25 "		
11 *A*	2-inch	$\frac{3}{4}$-inch	2.87 "			4.75 "		
1	$1\frac{1}{2}$-inch	$\frac{1}{2}$-inch		5.54 feet			9.50 feet	
2	$1\frac{1}{2}$-inch	$\frac{5}{8}$-inch		4.27 "			7.31 "	
3	2-inch	$\frac{3}{4}$-inch		4.12 "			7.07 "	
4	2-inch	$\frac{7}{8}$-inch		3.22 "			5.62 "	
1	2-inch	$\frac{1}{2}$-inch			6.23 feet			10.67 feet
2	2-inch	$\frac{5}{8}$-inch			5.68 "			9.72 "
3	2-inch	$\frac{7}{8}$-inch			4.10 "			7.02 "

The Spraco Nozzle is manufactured by the Spray Engineering Co., Boston, Mass.

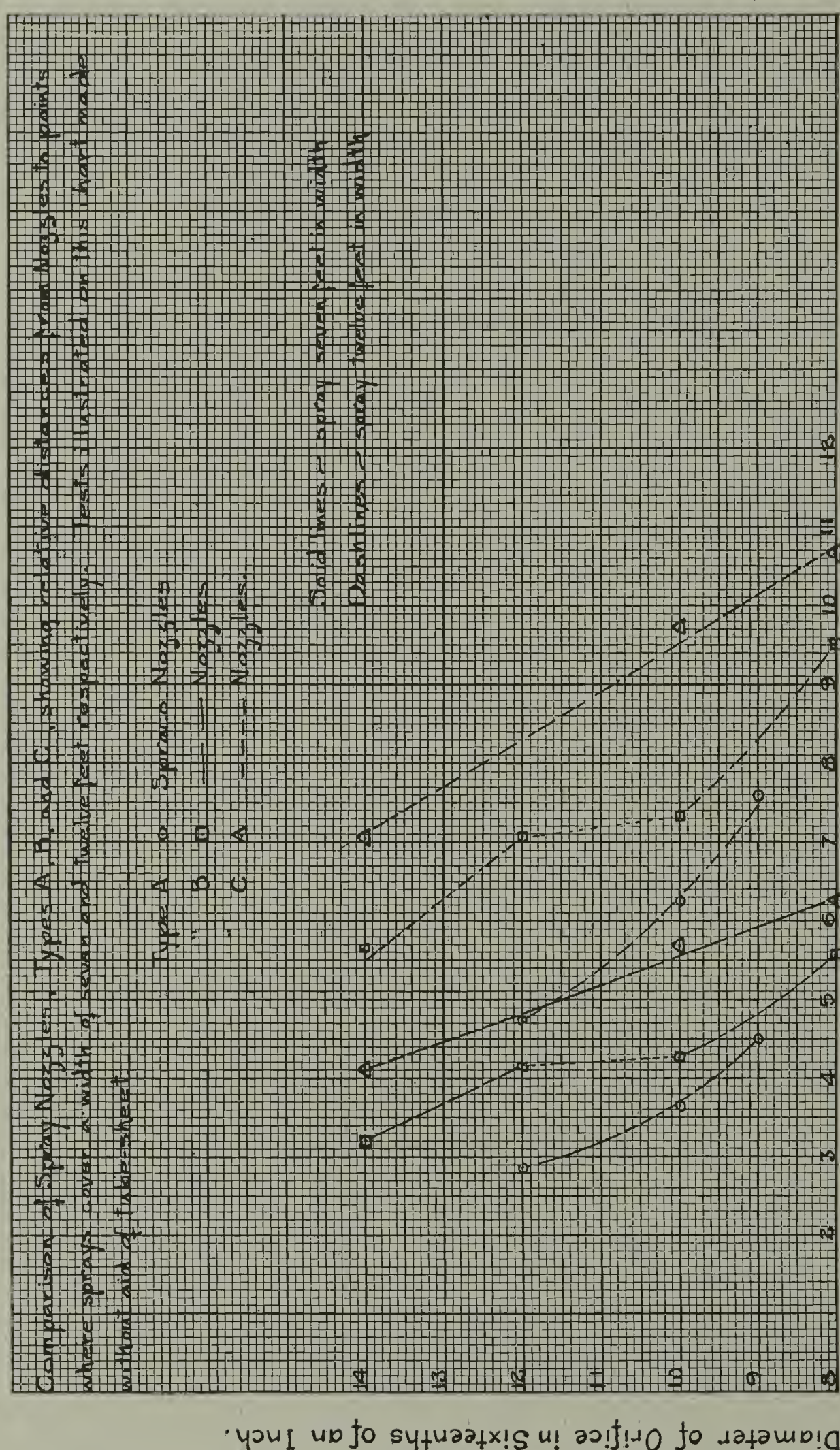


FIG. 19. Comparison of Spray Nozzles, Types A, B and C, showing relative distances from Nozzles to points where sprays cover a width of seven and twelve feet respectively. Tests illustrated on this chart made without aid of tube sheet. Type A Spraco Nozzles. Type B — — Nozzles. Type C - - - - Nozzles. Solid lines—spray seven feet in width. Dash lines—spray twelve feet in width.

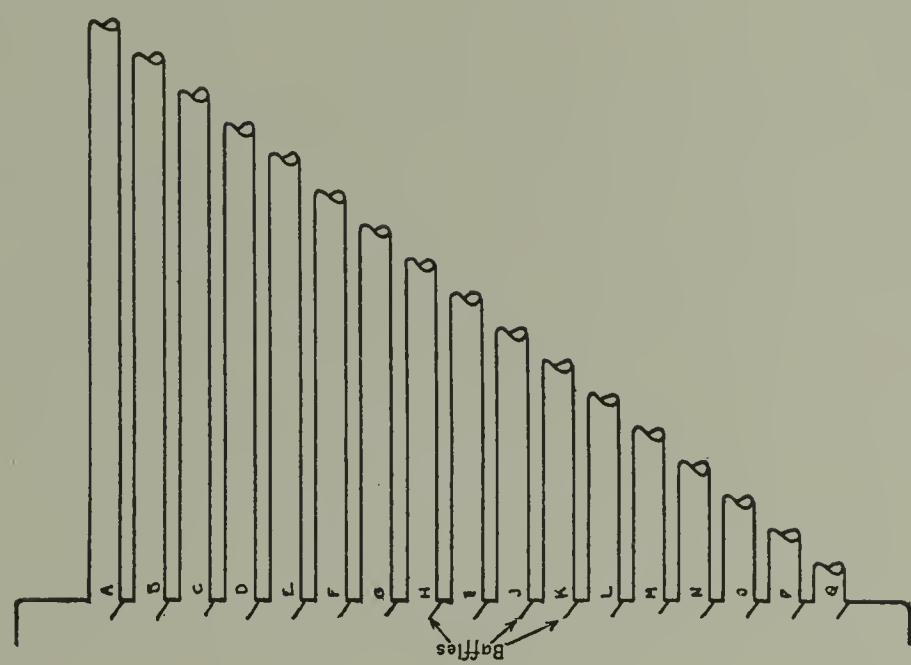


FIG. 20. Sketch of Tube-sheet used in test of Spray-nozzles. Baffles fitted to each row of tubes as shown.

TESTS OF SPRAY-NOZZLES USING TUBE-SHEET

Tests were then made of the uniformity of distribution of sprays over a vertical tube-sheet. The general arrangement, which may perhaps be better seen in the photographs, has already been shown in Figs. 20 and 21. The tube-sheet (½-inch iron-plate), 7 feet in diameter has 259 3-inch boiler-tubes expanded into the holes drilled as shown. On the feed-side of the sheet, a baffle-plate or trough was fitted snugly to the sheet, directly under each row of tubes and inclined upward so as to cover approximately one-half of the lower portion of each row, as shown in the figures and photograph 2. The entire sheet had a cylindrical shell attached, as seen in the photographs. Water was furnished by a six-inch centrifugal pump, through a four-inch line, the largest nozzle tested having a four-inch supply-pipe. The tubes were cut in various lengths to enable catching and measuring the volume delivered by separate tubes.

The distance between nozzle-tip and tube-sheet was such that the spray covered the entire sheet, the water striking the sheet being deflected from it and the side of the shell and caught by the baffles, or troughs, allowing all to run through the tubes.

Following are results of tests of Spraco nozzles using the tube-sheet as a means of measuring the uniformity of the distribution of

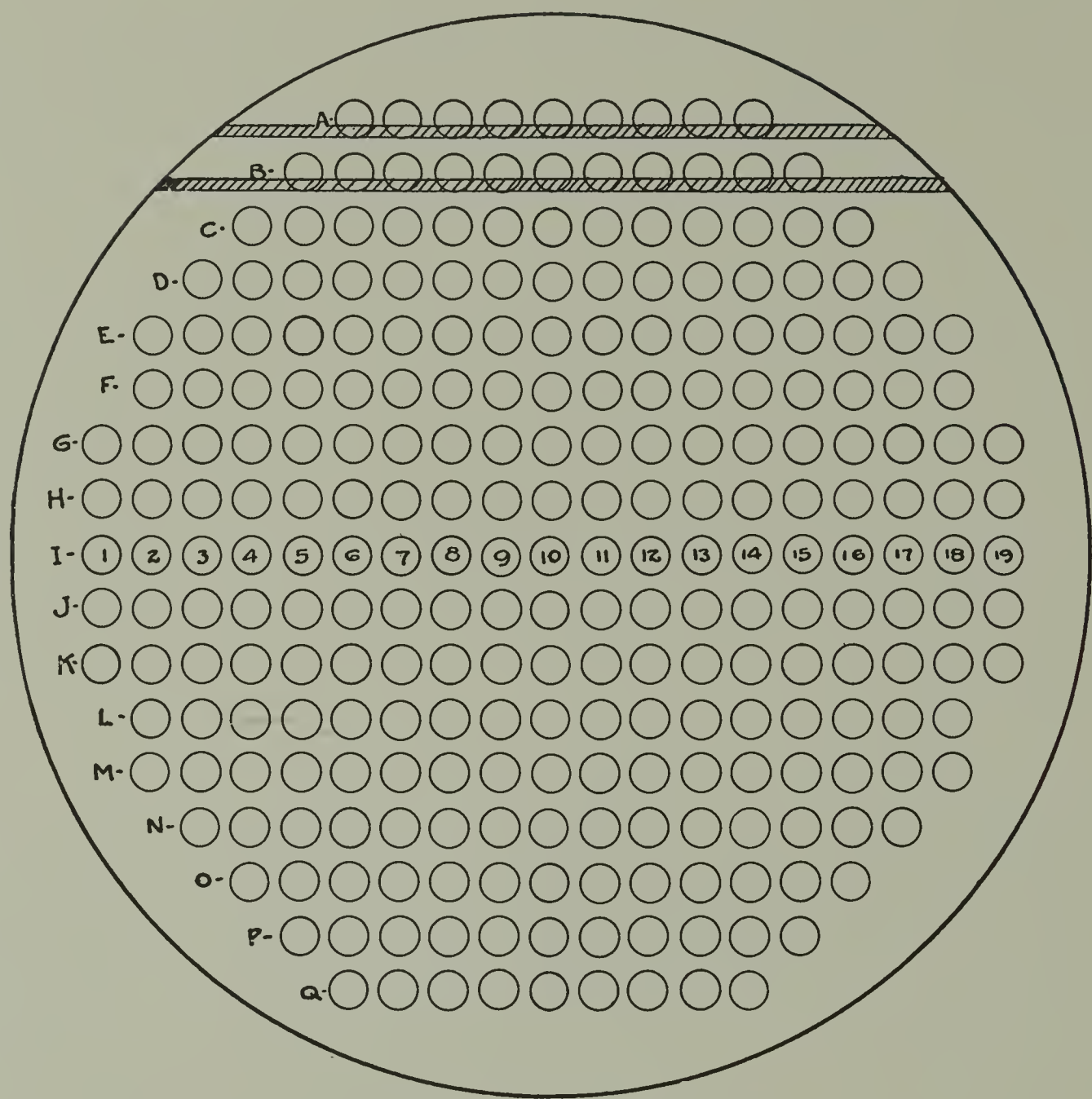


FIG. 21. Sketch of Tube-sheet used in test of Spray-nozzles. Tubes 3 inches O. D. with baffles fitted to sheet for each row of tubes as shown for Rows A and B. (See Fig. 1.)

the spray, each table being illustrated by an attached chart, each chart representing the tube-sheet as viewed from the front, i.e., from the nozzle. The particular tube delivering a certain amount of water may be located, from the tables, on the tube-sheet, by finding the number designated in the row across the center and reading directly up or down to the particular letter representing each row of tubes.

In making these tests every other tube was tested, rather than every tube, since an idea of the uniformity of the spray over the sheet and not exactly the precise amount of water issuing from the nozzles was sought for. A full explanation is given on each chart.

Throughout the tests made with the nozzle having a three-inch supply-pipe, the distance from the nozzle-tip to the tube-sheet was 3 feet 7 inches; and from the nozzle-tip to the floor of the shell surrounding the sheet 4 feet 1 inch.

In the case of the nozzle having the four-inch supply-pipe, the corresponding distances were 3 feet 3 inches, and 4 feet, respectively.

No figures are attached to the chart showing the distribution of the spray delivered by the nozzle with 3-inch supply-pipe at a pressure of 10 lbs. per sq. in. Higher pressures than 15 lbs. per sq. in. were not used with the nozzle having a 4-inch supply-pipe, because at these higher pressures, water striking the upper parts of the sheet splashed over the troughs and fell back into the shell. At present, wider troughs are being made which it is hoped will remedy this difficulty.

Table VI shows the distribution of a Spraco Nozzle with 3-inch supply-pipe under 9 lbs. pressure per square inch. Table VII shows the distribution of the same nozzle under 15 lbs. pressure per square inch. Table VIII shows the distribution of the same nozzle under 20 lbs. pressure per square inch. Table IX shows the distribution of the same nozzle under 25 lbs. pressure per square inch. Table X shows the distribution of a spraco nozzle with 4-inch supply-pippe under 10 lbs. pressure per square inch. Table XI shows the distribution of the same nozzle under 15 lbs. pressure per square inch. I submit two tables, viz., Tables XII and XIII showing the capacities of spraco nozzles under different pressures.

In a general way the characteristics of several nozzles will be illustrated by photographs which follow.

In almost all evaporators we have a storage of liquor in each effect to come and go upon and thus the regulation from effect to effect can be hand-controlled by valves. In the type shown we have no storage capacity and thus a new problem enters into the running of such an evaporator. If no liquor passes through the tubes of any effect the evaporator ceases to function. In order to overcome this difficulty it becomes absolutely necessary to have some device which will automatically control each evaporator. Such a device is preferably a float valve so piped up that the level of the liquor in the exit well of the evaporator shall control the amount of spray entering such an evaporator. Fig. 22 shows such a valve designed for this

TABLE VI

Spraco Nozzle—3-inch supply-pipe.

3 feet 6 inches from nozzle-tip to tube-sheet.

4 feet 2 inches above bottom of shell.

Test made before additional part was added to top of shell. Pressure, 9 lbs. per sq. in.

Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute
A	14	.288	*H*	19	.682	*N*	17	.228
	12	.206		15	.469		15	.143
	9	.176		10	.715		10	.273
	6	.455		5	.416		5	.166
B	15	.555		1	.682		3	.214
	12	.333	*I*	19	.682	*O*	16	.313
	9	.341		15	.441		10	.170
	5	.517		10	.682		4	.395
C	16	.577		5	.441	*P*	15	.254
	12	.429		1	.500		10	
	9	.429	*J*	19	.625		5	
	5	.375		15	.429	*Q*	14	Slow
D	17	.652		10	.455		10	Delivery
	13	.366		5	.429		6	
	8	.416		1	.555			
	4	.500	*K*	19	.167			
E	18	.517		15	.385			
	14	.429		10	.429			
	10	.455		5	.406			
	5	.366		1	.375			
	2	.715	*L*	18	.250			
F	18	.625		15	.341			
	15	.395		10	.535			
	11	.395		5	.441			
	7	.350		2	.500			
	4	.395	*M*	18	.162			
	2	.790		15	.231			
G	19	.500		10	.469			
	15	.416		5	.375			
	10	.469		2	.484			
	5	.416						
	1	.288						

TABLE VII

Spraco Nozzle—3-inch supply-pipe.
43 inches from nozzle-tip to tube-sheet.
49 inches above floor of shell. Pressure, 15 lbs. per sq. in.

Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute
A	6	.319	*F*	16	.600	*K*	1	.341	*O*	16	Delivery for O, P, Q similar to that for O, P, Q at 20 lbs./sq. in.
	8	.220		18	1.250		3	.405	*P*	5	
	10	.227	*G*	1	.790		5	.625		7	
	12	.294		3	.500		7	.750		9	
	14	.577		5	.625		9	.682		11	
B	5	.349		7	.600		11	.715		13	
	7	.300		9	.750		13	.833		15	
	9	.405		11	.750		15	.715	*Q*		
	11	.341		13	.682		17	.518			
	13	.375		15	.600		19	.715			
	15	.682		17	.652	*L*	2	.366			
C	4	.883		19	.625		4	.477			
	6	.469	*H*	1	1.250		6	.682			
	8	.535		3	.517		8	.750			
	10	.500		5	.750		10	.682			
	12	.535		7	.750		12	.682			
	14	.535		9	.939		14	.750			
	16	1.000		11	1.000		16	.625			
D	3	.750		13	.715		18	.939			
	5	.469		15	.577	*M*	2	.254			
	7	.555		17	.715		4	.306			
	9	.600		19	1.152		6	.555			
	11	.577	*I*	1	1.250		8	.715			
	13	.625		3	.441		10	.715			
	15	.535		5	.750		12	.715			
	17	1.500		7	.750		14	.682			
E	2	.750		9	.939		16	.441			
	4	.555		11	1.152		18	.790			
	6	.652		13	.790	*N*	3	.250			
	8	.555		15	.750		5	.208			
	10	.469		17	.600		7	.397			
	12	.600		19	.883		9	.500			
	14	.600	*J*	1	1.000		11	.385			
	16	.652		3	.375		13	.294			
	18	1.500		5	.682		15	.238			
F	2	1.000		7	.750		17	.358			
	4	.555		9	.750	*O*	4				
	6	.555		11	.790		6				
	8	.484		13	.715		8				
	10	.469		15	.750		10				
	12	.535		17	.500		12				
	14	.469		19	1.500		14				

TABLE VIII

Spraco Nozzle—3-inch supply-pipe.
43 inches from nozzle-tip to tube-sheet.
49 inches above floor of shell. Pressure, 20 lbs. per sq. in.

Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute
A	6	.357	*F*	16	.600	*K*	1	.455	*O*	16	.429
	8	.273		18	1.152		3	.469	*P*	5	
	10	.294	*G*	1	1.071		5	.750		7	
	12	.326		3	.682		7	.939		9	
	14	.682		5	.790		9	.790		11	
B	5	.500		7	.682		11	.833		13	
	7	.406		9	.833		13	.883		15	
	9	.484		11	.939		15	.750	*Q*		
	11	.441		13	.682		17	.469			Slow delivery
	13	.470		15	.750		19	.517			
	15	.750		17	.750	*L*	2	.455			
C	4	1.000		19	.750		4	.484			
	6	.577	*H*	1	1.500		6	.883			
	8	.652		3	.682		8	.883			
	10	.652		5	.883		10	1.000			
	12	.682		7	.883		12	.883			
	14	.625		9	1.250		14	.682			
	16	1.152		11	1.152		16	.484			
D	3	1.000		13	.790		18	.715			
	5	.600		15	.683	*M*	2	.300			
	7	.600		17	.750		4	.319			
	9	.652		19	1.152		6	.625			
	11	.682	*I*	1	1.364		8	.833			
	13	.715		3	.555		10	.883			
	15	.652		5	.833		12	.883			
	17	1.500		7	.883		14	.682			
E	2	1.000		9	1.250		16	.406			
	4	.577		11	1.250		18	.600			
	6	.682		13	.939	*N*	3	.231			
	8	.600		15	.790		5	.250			
	10	.555		17	.625		7	.417			
	12	.750		19	.833		9	.535			
	14	.750	*J*	1	1.152		11	.517			
	16	.682		3	.500		13	.375			
	18	1.364		5	.833		15	.221			
F	2	1.152		7	.883		17	.273			
	4	.652		9	.883	*O*	4	.417			
	6	.625		11	.883		6	.250			
	8	.517		13	.883		8	.278			
	10	.600		15	.883		10	.283			
	12	.652		17	.469		12	.268			
	14	.625		19	1.071		14	.208			

TABLE IX

Spraco Nozzle—3-inch supply-pipe.
43 inches from nozzle-tip to tube-sheet.
49 inches from floor of shell. Pressure, 25 lbs. per sq. in.

Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute
A	6	.790	*F*	16	.715	*K*	1	.652	*O*	16	.578
	8	.682		18	1.875		3	.577	*P*	5	
	10	.517	*G*	1	1.500		5	.750		7	
	12	.535		3	.939		7	.883		9	
	14	1.000		5	.883		9	.715		11	
B	5	1.071		7	.682		11	.625		13	
	7	.517		9	.715		13	.883		15	
	9	.484		11	.715		15	.939	*Q*		
	11	.366		13	.625		17	.939			
	13	.429		15	.939		19	1.000			
	15	.939		17	1.000	*L*	2	.750			
C	4	1.500		19	1.071		4	.555			
	6	.600	*H*	1	1.875		6	.833			
	8	.517		3	1.000		8	.833			
	10	.405		5	.939		10	.715			
	12	.455		7	.939		12	.682			
	14	.484		9	1.071		14	.790			
	16	1.250		11	1.000		16	.600			
D	3	1.666		13	.833		18	1.071			
	5	.682		15	1.250	*M*	2	.500			
	7	.484		17	1.250		4	.441			
	9	.455		19	3.000		6	.750			
	11	.405	*I*	1	1.666		8	.750			
	13	.429		3	.750		10	.682			
	15	.577		5	1.000		12	.682			
	17	1.875		7	.939		14	.682			
E	2	1.875		9	1.071		16	.500			
	4	.790		11	1.071		18	.833			
	6	.715		13	1.250	*N*	3	.429			
	8	.500		15	1.666		5	.341			
	10	.366		17	1.500		7	.517			
	12	.395		19	1.875		9	.535			
	14	.555	*J*	1	1.364		11	.469			
	16	.715		3	.600		13	.385			
	18	1.666		5	.790		15	.250			
F	2	1.875		7	1.000		17	.357			
	4	.939		9	.790	*O*	4	.385			
	6	.652		11	.833		6	.234			
	8	.517		13	1.000		8	.294			
	10	.417		15	1.071		10	.294			
	12	.417		17	.883		12	.294			
	14	.440		19	1.875		14	.250			

Slow delivery.

TABLE X

Spraco Nozzle—4-inch supply-pipe
39 inches from nozzle-tip to the tube-sheet.
48 inches from floor of shell. Pressure, 10 lbs. per sq. in.

Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute
A	6	.485	*G*	1	1.875	*K*	7	1.000	*P*	11	.429
	8	.341		3	.834		9	.939		13	.250
	10	.341		5	.577		11	.883		15	.214
	12	.500		7	.484		13	.625	*Q*	Low flow	
	14	.834		9	.834		15	1.000			
B	5	1.000		11	1.374		17	.939			
	7	.790		13	1.071		19	1.071			
	9	.939		15	1.000	*L*	2	1.250			
	11	1.000		17	1.000		4	1.250			
	13	.790		19	1.000		6	1.500			
	15	.883	*H*	1	2.500		8	1.250			
C	4	1.875		3	1.071		10	.834			
	6	1.000		5	.750		12	.750			
	8	1.250		7	.750		14	1.071			
	10	1.152		9	1.500		16	1.250			
	12	1.250		11	1.875		18	1.500			
	14	1.250		13	1.250	*M*	2	1.500			
	16	3.000		15	.939		4	1.250			
D	3	1.875		17	.939		6	1.875			
	5	.750		19	1.666		8	1.364			
	7	.790	*I*	1	2.500		10	1.364			
	9	.835		3	1.152		12	1.666			
	11	1.000		5	1.000		14	1.875			
	13	1.000		7	1.000		16	.939			
	15	1.000		9	1.500		18				
	17	1.000		11	1.875	*N*	3	.375			
E	2	2.140		13	1.152		5	.652			
	4	.750		15	1.000		7	1.364			
	6	.682		17	1.000		9	1.875			
	8	.555		19	1.500		11	1.666			
	10	.500	*J*	1	2.500		13	1.071			
	12	.883		3	1.152		15	.715			
	14	.939		5	1.364		17	.555			
	16	.939		7	1.071	*O*	4	.300			
	18	.939		9	1.250		6	.450			
F	2	2.140		11	1.152		8	.715			
	4	.682		13	.750		10	1.152			
	6	.485		15	.939		12	1.071			
	8	.455		17	.834		14	1.071			
	10	.652		19	1.666		16	.750			
	12	1.071	*K*	1	1.250	*P*	5	.283			
	14	.939		3	1.152		7	.214			
	16	.790		5	1.364		9	.500			
	18	1.875									

TABLE XI

Spraco Nozzle—4-inch supply-pipe.
39 inches from nozzle-tip to tube-sheet.
48 inches from floor of shell. Pressure, 15 lbs. per sq. in.

Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute	Row	Tube	Gals. per Minute
A	6	.652	*F*	16	1.152	*K*	1	1.500	*O*	16	.600
	8	.429		18	3.000		3	1.071	*P*	5	
	10	.429	*G*	1	2.500		5	1.875		7	
	12	.600		3	1.071		7	1.500		9	
	14	1.071		5	.833		9	1.500		11	
B	5	1.250		7	.600		11	1.152		13	
	7	1.071		9	1.071		13	1.000		15	
	9	1.071		11	1.500		15	1.152	*Q*		
	11	1.364		13	1.666		17	1.000			
	13	1.364		15	1.250		19	1.250			
	15	3.000		17	.939	*L*	2	1.364			
C	4	3.000		19	1.666		4	1.152			
	6	1.500	*H*	1	2.140		6	1.875			
	8	1.666		3	1.500		8	1.500			
	10	1.666		5	1.071		10	1.152			
	12	1.875		7	1.500		12	1.071			
	14	1.875		9	1.875		14	1.500			
	16	5.000		11	2.140		16	1.500			
D	3	3.750		13	1.500		18	1.666			
	5	.939		15	1.152	*M*	2	.750			
	7	1.152		17	1.364		4	.885			
	9	1.071		19	1.875		6	2.140			
	11	1.500	*I*	1	3.000		8	1.500			
	13	1.364		3	1.500		10	1.364			
	15	1.364		5	1.500		12	1.875			
	17	3.000		7	1.364		14	2.500			
E	2	3.000		9	2.500		16	1.364			
	4	1.000		11	2.500		18	1.509			
	6	.939		13	1.500	*N*	3	.366			
	8	.750		15	1.152		5	.600			
	10	.715		17	1.250		7	1.666			
	12	1.364		19	1.666		9	2.140			
	14	1.364	*J*	1	2.500		11	1.666			
	16	1.364		3	1.364		13	1.500			
	18	3.750		5	1.666		15	.750			
F	2	2.500		7	1.875		17	.600			
	4	.883		9	2.140	*O*	4	.254			
	6	.652		11	1.500		6	.341			
	8	.625		13	.883		8	.883			
	10	.883		15	1.152		10	.625			
	12	1.364		17	1.000		12	1.152			
	14	1.152		19	2.140		14	.652			

Low flow.

TABLE XII

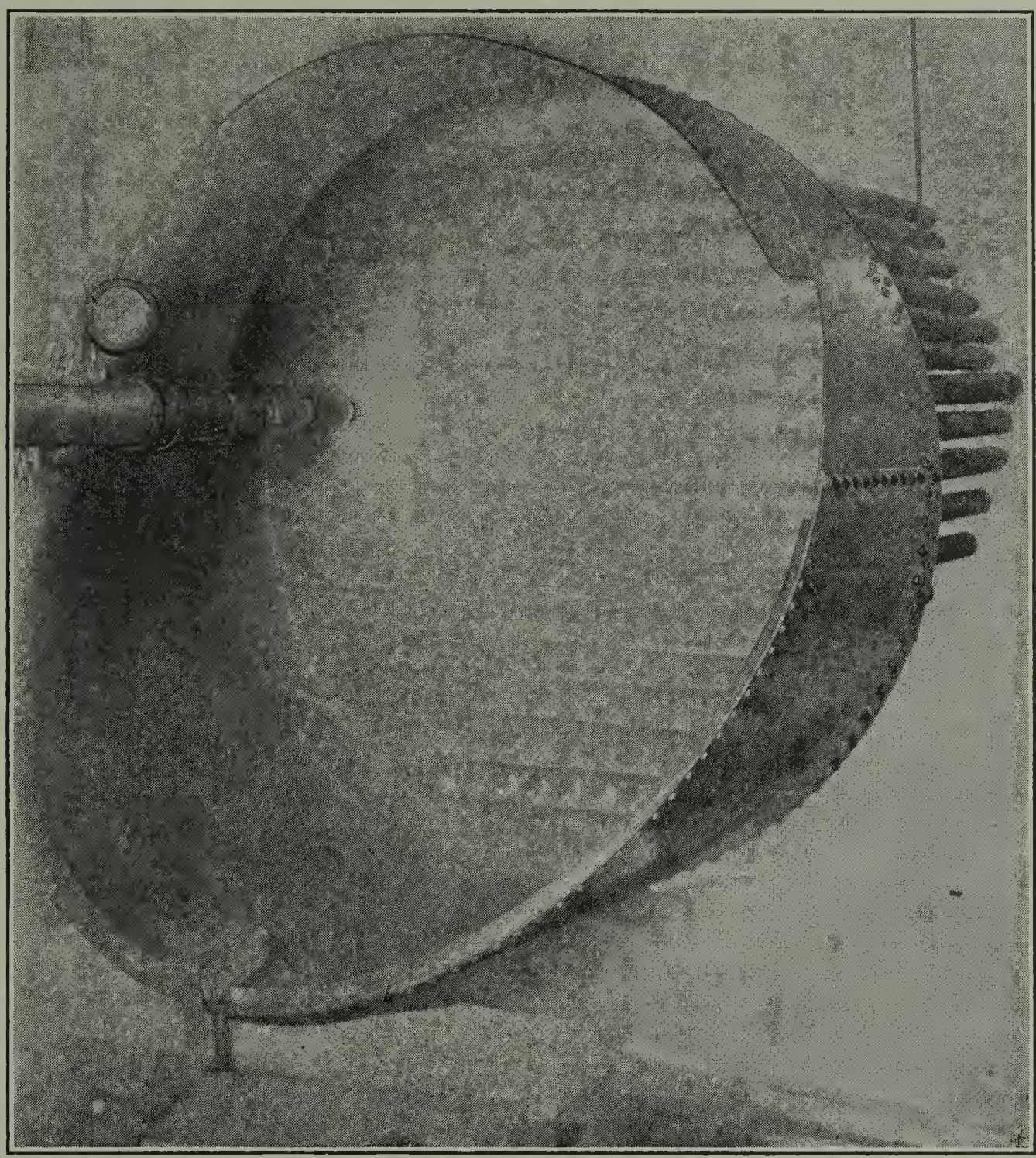
SPRAY ENGINEERING COMPANY

Table of Capacities of Small Spraco Nozzles

No.	Dia. of Orifice	Supply Pipe	Overall Length	Capacity in Gals. of Water per Minute at Different Pressures. Pressure in Lbs. per Square Inch									
				5	10	15	20	25	30	40	50	75	100
1–*S*....	025″	$\frac{1}{4}$″	$1\frac{7}{16}$″	.021	.031	.038	.043	.049	.054	.063	.07	.084	.098
1–*B*....	$\frac{3}{64}$″	$\frac{1}{4}$″	$1\frac{1}{4}$″	.07	.11	.13	.15	.17	.18	.21	.24	.29	.34
2–*B*....	$\frac{1}{16}$″	$\frac{1}{4}$″	$1\frac{3}{8}$″	.14	.21	.26	.30	.33	.36	.42	.47	.57	.65
3–*B*....	$\frac{5}{64}$″	$\frac{1}{4}$″	$1\frac{1}{2}$″	.23	.33	.40	.46	.51	.56	.65	.73	.89	1.02
4–*D*....	089″	$\frac{3}{8}$″	$1\frac{11}{16}$″	.37	.50	.60	.69	.77	.84	.95	1.06	1.30	1.52
5–*B*....	$\frac{1}{8}$″	$\frac{3}{8}$″	$1\frac{11}{16}$″	.63	.94	1.16	1.36	1.51	1.66	.90	2.08	2.48	2.74
6–*B*....	$\frac{3}{16}$″	$\frac{1}{2}$″	$2\frac{5}{8}$″	1.90	2.65	3.18	3.62	4.03	4.42	1.06	5.59	6.61	7.40
7–*B*....	$\frac{1}{4}$″	$\frac{3}{4}$″	$2\frac{3}{4}$″	3.7	5.2	6.3	7.3	8.1	8.9	5.3	11.4	13.9	
8–*A*....	$\frac{5}{16}$″	1″	$2\frac{7}{8}$″	5.3	7.6	9.3	10.7	12.0	13.0	10.5	16.0		
9–*A*....	$\frac{3}{8}$″	$1\frac{1}{4}$″	$3\frac{3}{4}$″	7.7	11.2	13.7	15.7	17.6	10.0	21.7	24.0		
10–*A*....	$\frac{1}{2}$″	$1\frac{1}{2}$″	4″	12.2	17.5	21.3	24.6	27.5	30.1	34.2	37.4		

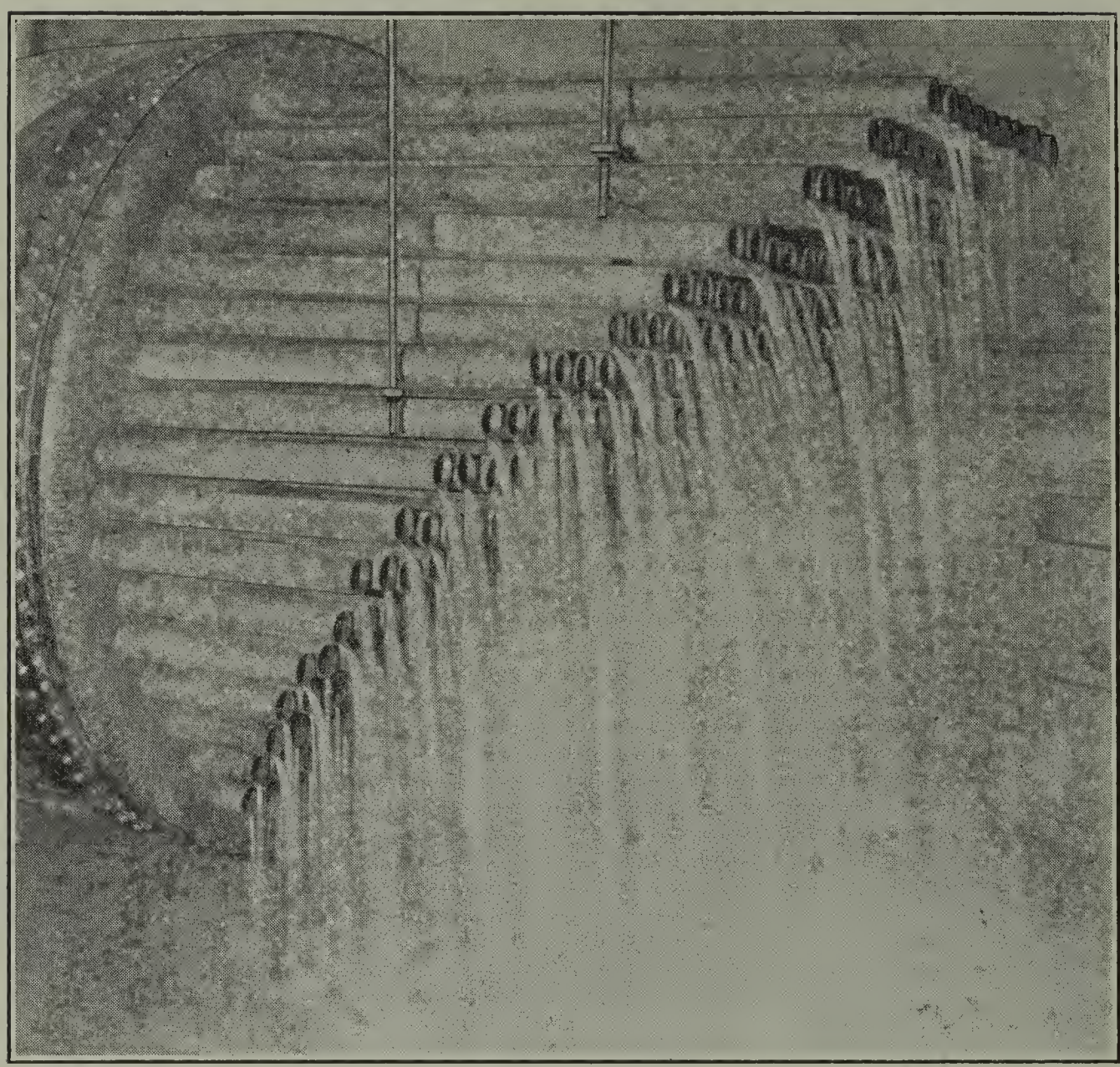
Use only pressures to right of this line.

Note: Shells of nozzles of all sizes up to No. 6-*B* inclusive, made in two parts.



PHOTOGRAPH I

Type of nozzle: Spraco.
Made by: Spray Engineering Co., Boston, Mass.
Size: 3-inch supply-pipe.
Pressure: 25 lbs. per sq. in.
Nozzle-tip 3½ feet from tube-sheet and 4 feet above floor of shell.
Showing general arrangement of nozzle and tube-sheet from front end.

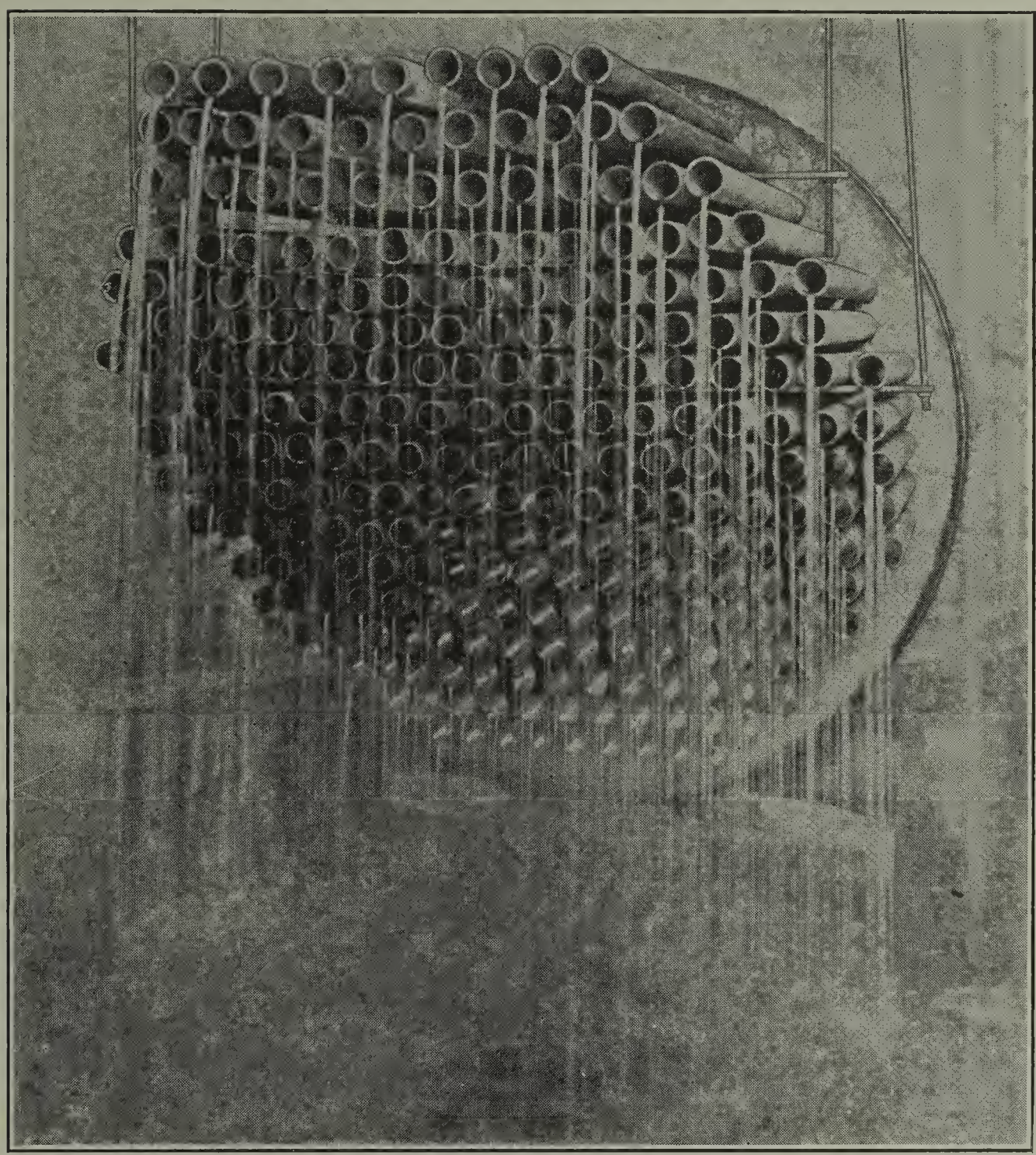


PHOTOGRAPH 2

Type of nozzle: Spraco.
Made by: Spray Engineering Co., Boston, Mass.
Size: 3-inch supply-pipe.
Pressure: 25 lbs. per sq. in.

Nozzle-tip 3½ feet from tube-sheet and 4 feet above floor of shell.

Viewed from the side, showing the uniformity of distribution. In this case all the tubes are delivering water.



PHOTOGRAPH 3

Type of nozzle: Type B.
Made by: .....
Size: No. .....
Pressure: 22½ lbs. per sq. in.

Viewed from delivery end, showing that most of the spray is delivered by the outer rows of tubes.

TABLE XIII

SPRAY ENGINEERING COMPANY

Table of Capacities of Large Spraco Nozzles

No.	Dia. of Orifice	Pipe Tap	Overall Length	Capacity in Gal. per Min. at Different Pressures. Pressure in Lbs. per Square Inch					
				5 lb.	6 lb.	7 lb.	8 lb.	10 lb.	15 lb.
10 B–*A*.	$\frac{19}{32}''$	$1\frac{1}{2}''$	$4\frac{1}{4}''$	19	20	21.5	23	25	31
11 *A* . . .	$\frac{3}{4}''$	$2''$	$4\frac{3}{4}''$	33.5	37	40	42.5	48	58.5
11 *B*–*A*.	$\frac{15}{16}''$	$2''$	$5''$	53	58	62	65.5	72	85
12 *B* . . .	$1\frac{11}{16}''$	$2\frac{1}{2}''$	$6''$	70	77	83	88	100	123
13 *A* . . .	$1\frac{15}{16}''$	$3''$	$7\frac{1}{2}''$	116	120	125	130	140	170

purpose. As pressures vary from time to time in the evaporators, it is necessary to have a valve which works independently of any pressures. The liquor into each evaporator is controlled by its valve

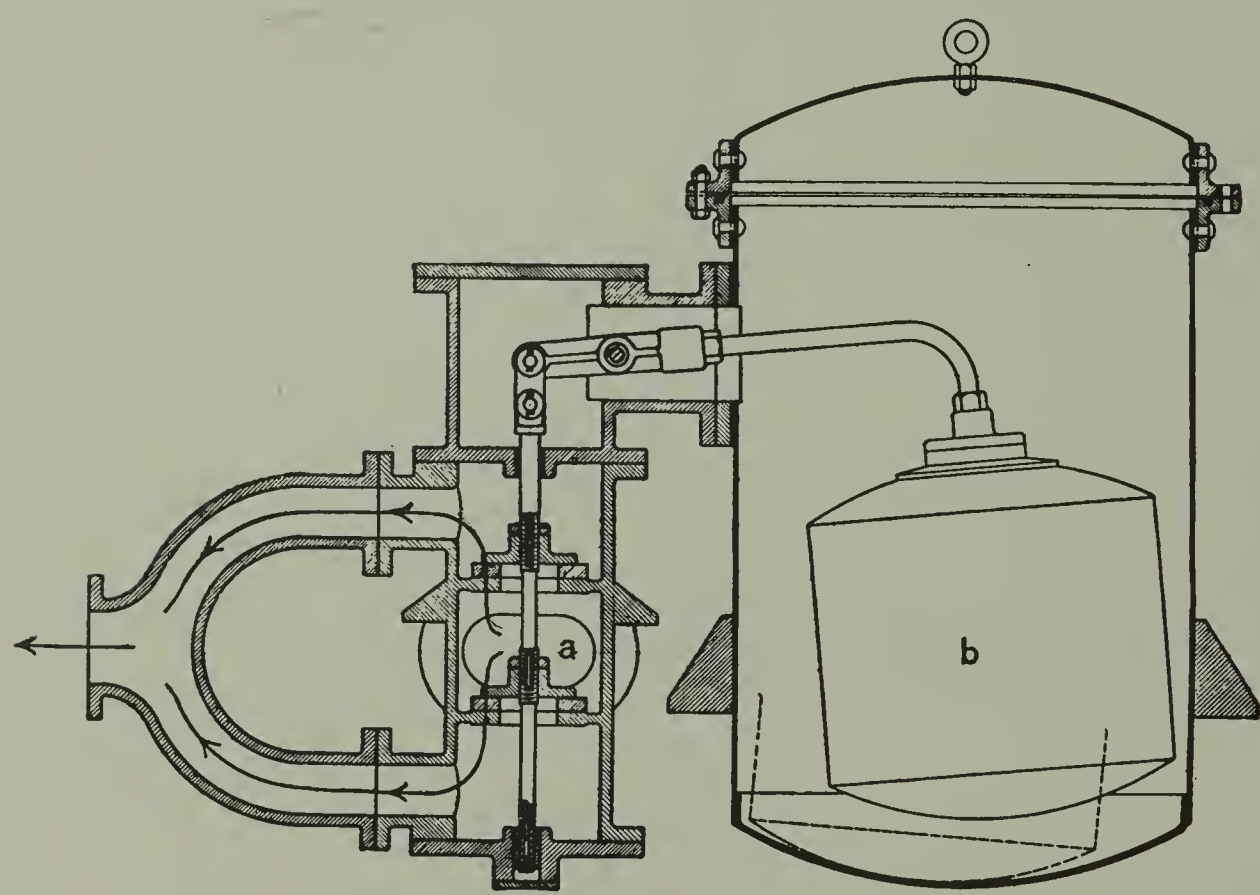


FIG. 22. Arrows show course of liquor which enters at *a*, *b* = float.

and the force is supplied by a centrifugal pump situated 36′ below the bottom of the exit well. It will readily be seen that a series of valves like the above responds to any change made in the rate of discharge from the final evaporation and may be compared to a row

of blocks set on end, wherein if you tip one block the others fall down, differing, however, from the illustration in that both choking and opening the final liquor discharge chokes and opens each valve accordingly, while picking up one block does not pick up the other blocks.

The ebullition area may be considered as the product of the diameter, tube length, and number of tubes. Up to date we have been unable to observe any foaming even with the most foamy liquors. Instead of having a sufficient pressure on a preceding effect to raise the liquor to the height of the top level of tubes, we accomplish the same result, as well as the pressure necessary to operate the spray nozzles, by electrically driven pumps.

It will be seen that any scale in such an evaporator may be removed by surrounding the tubes with water and cracking off the scale by means of an acetylene flame.

This type of evaporator can be increased in capacity by taking apart the back flange, adding a section, and increasing the length of the tubes, which can be lengthened to the desired length by an electric welding machine.

This article is not for the purpose of sponsoring any one type of evaporator and so I feel some hesitancy in showing the type which we use. But having laid down certain principles of evaporation, it becomes necessary to show at least one method by which these principles can be put into actual practice. I have therefore had a working drawing photographed at a greatly reduced scale, in order that a general idea of the type may be obtained. I therefore submit Fig. 23. The gill flanges are not shown on this photograph, though two are indicated. Photograph 1, however, shows these gill flanges and so their absence is not material.

In relation to the special float valve shown in Fig. 22, it will be observed that by putting the disks or seats (*a*) below the partitions (*b*), the drop of the float will close the valve instead of open it as shown in the chart.

If the liquor to be evaporated is of such a nature as to make it impossible to take out a 50 per cent liquor from the vacuum effect, and comes to the evaporator at a high temperature, the greatest efficiency will be obtained by passing the liquor through an exchanger and then entering it in an intermediate effect. The effect which it

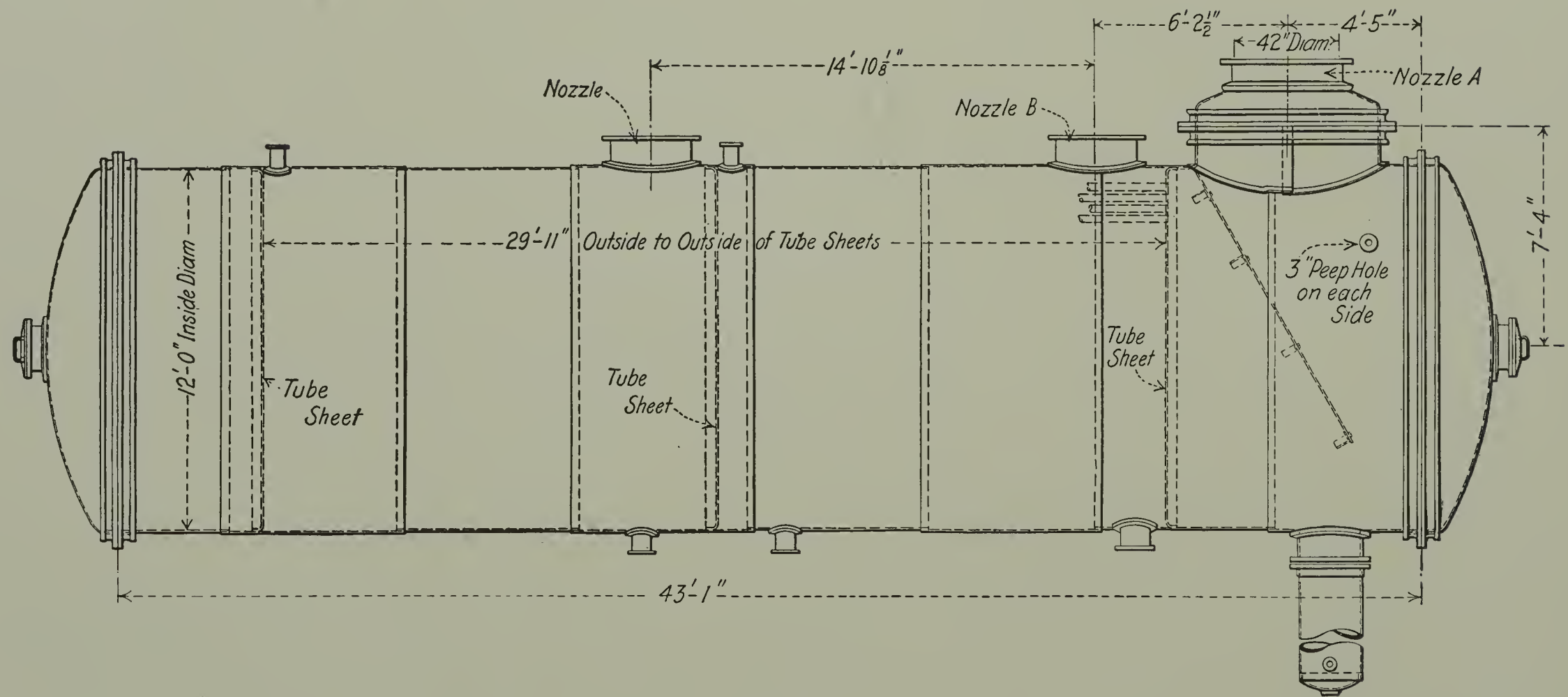

6'-2½"
4'-5"
42" Diam.
Nozzle A
14'-10⅛"
Nozzle
Nozzle B
7'-4"
29'-11" Outside to Outside of Tube Sheets
12'-0" Inside Diam
3" Peep Hole on each Side
Tube Sheet
Tube Sheet
Tube Sheet
43'-1"

Fig 23.

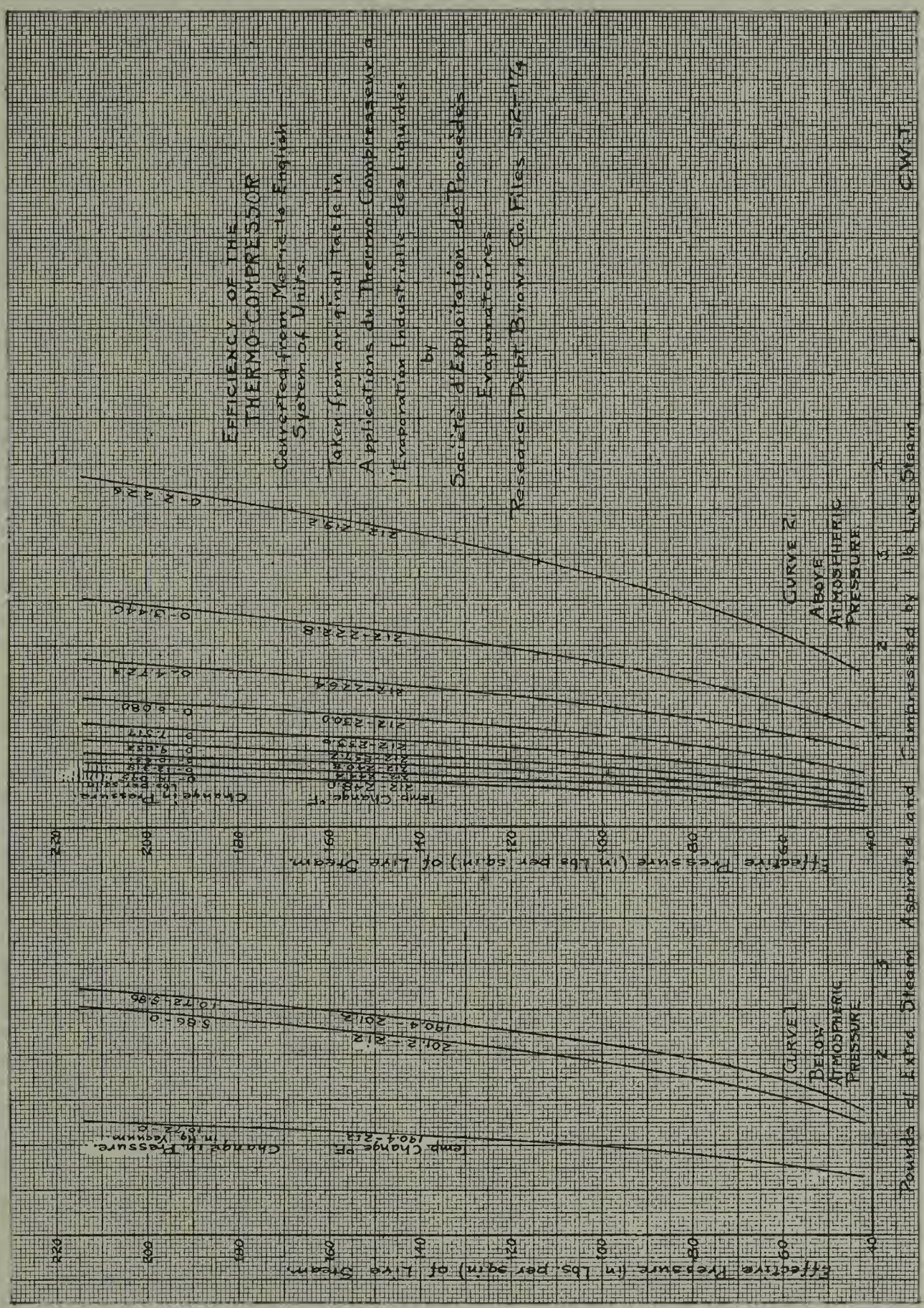


FIG. 24. Efficiency of the Thermo-Compressor. Converted from Metric to English System of Units. Taken from original table in Applications du Thermo-Compresseur à l'Evaporation Industrielle des Liquides, by Société d'Exploitation de Procédés Evaporatoires. Research Dept., Brown Co.

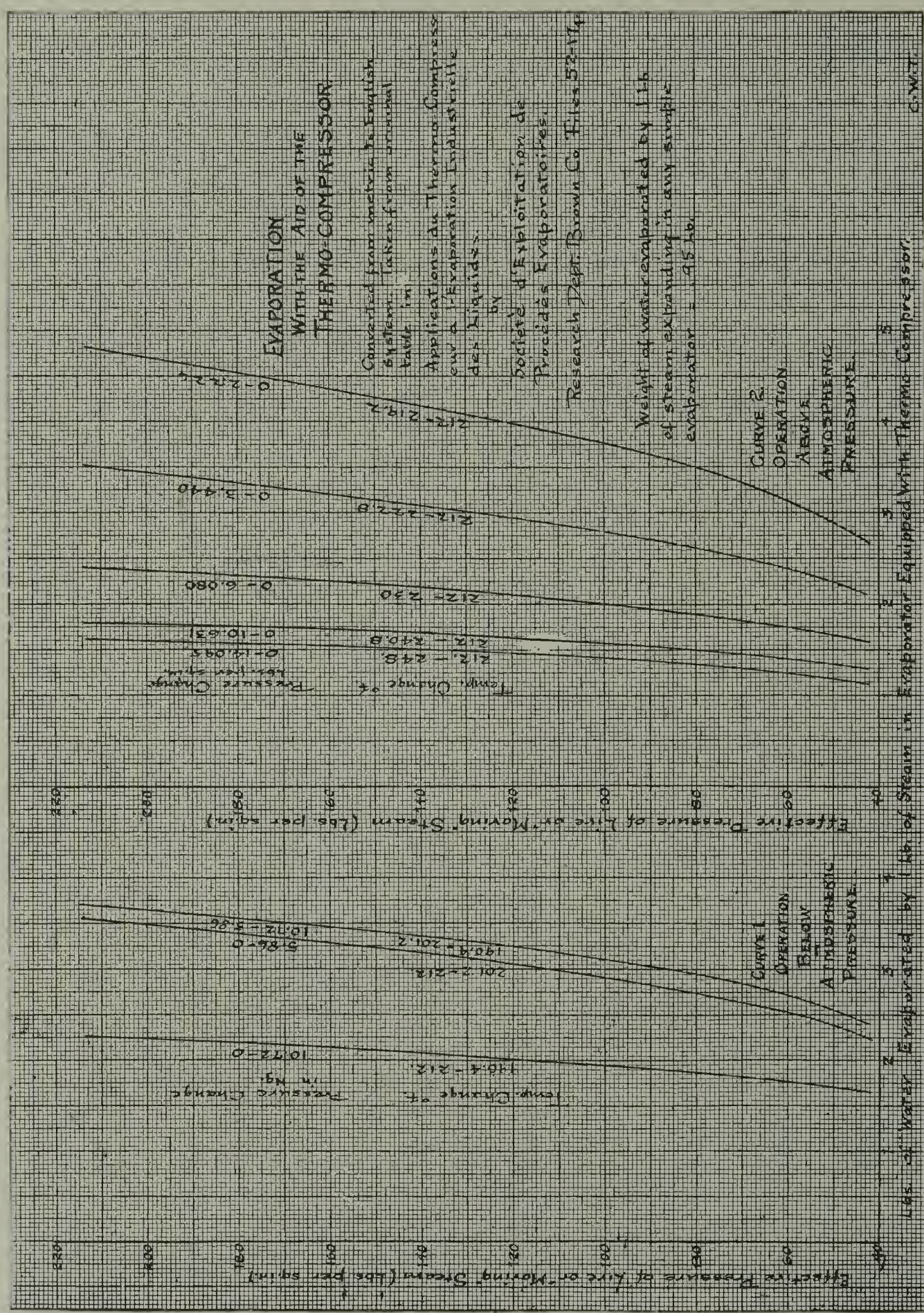


FIG. 25. Evaporation with the Aid of the Thermo-Compressor. Converted from Metric to English System. Taken from original table in Applications du Thermo-Compresseur à l'Evaporation Industrielle des Liquides, by Société d'Exploitation de Procédés Evaporatoires. Research Dept., Brown Co. Weight of water evaporated by 1 lb. of steam expanding in any simple evaporator = .95 lb.

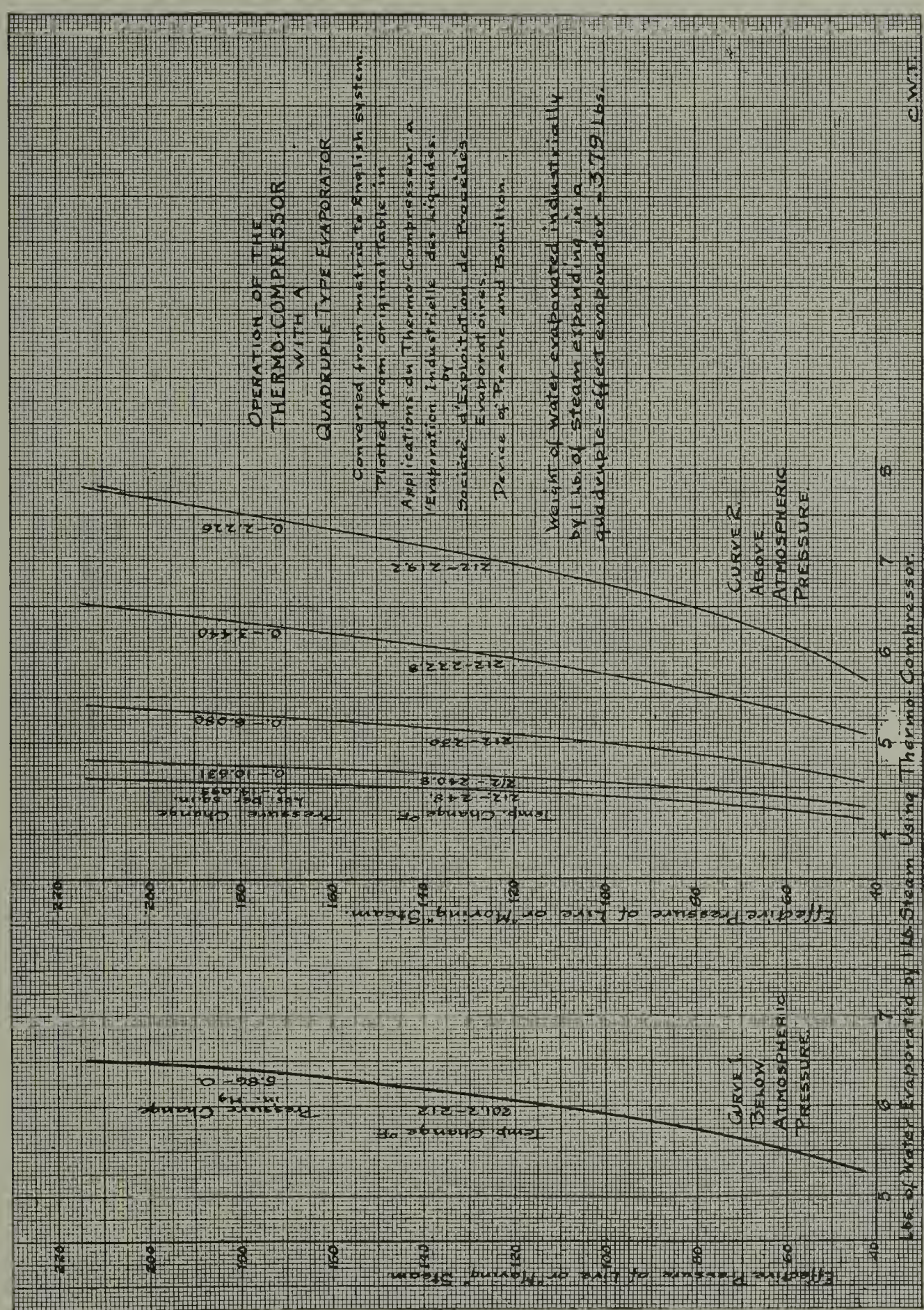


Fig. 26. Operation of the Thermo-Compressor with a Quadruple Type Evaporator.

enters is determined by the temperature of the liquor after it has passed through the exchanger. The liquor is then passed in forward or parallel flow evaporation and after emerging from the last effect is passed through the exchanger above mentioned, entering the next preceding effect of the one which received the weakest liquor and submitted to backward or counter-current evaporation. By this means the concentrated liquor may emerge from the hottest evaporator at a temperature at which the viscosity is so reduced as to obviate the difficulties encountered in forward flow evaporation.

There are many combinations in the sequence of evaporation, which I will not go into here, as this paper, even with the vigorous pruning which it has undergone, is unduly long. Sometimes an intermediate process is interjected into some intermediate style of evaporation, but I can not discuss this at this time. I had intended to go into the discussion of thermo-compression, but owing to the above reason, and also that L. A. Pridgeon has already given an excellent paper on this subject, I will simply include Figs. 24, 25, and 26, which need no explanation.

It will be seen from the above that by observing all the principles outlined in this article it is possible to design an evaporator for sulphite liquor which will evaporate so cheaply that the fuel value alone will furnish heat enough to do the evaporating of the liquor and leave an excess which will cut down the use of coal to such an extent that substantial dividends can be paid upon the whole installment.

There are many uses other than fuel to which sulphite liquor may be put, but as this is a paper on evaporation I will not go into this matter here. If this sulphite liquor is to be used as a fuel, it can be dried by either atomizing through furnace gases or used in the method already explained in the explosion process, using an oxidizing atmosphere rather than a reducing atmosphere.

In conclusion, I wish to acknowledge my indebtedness to Carl Gunsel for his help in the preparation of the charts and his most efficient work in superintending the experiments from which the data have been obtained, also to John Graff for the photographic material.

Note 1.—It will be noted in the above article that nearly all the tabular data upon which the charts are based have been omitted. The reason for this is that there is so much of it that it would con-

sume many times the space required by the article as it is. The only tabular data included are those which must be included because they can not be obtained from the charts.

Note 2.—On many of the curves the points given by the tabular data are not plotted because these curves come so near together that if points were placed thereon the curves would be valueless for the purpose to which they are submitted.

Discussion

Mr. H. K. Moore (continuing): Many of you will have questions that you want to ask. Perhaps I might state that the Brown Company expects to put in an evaporator of 10 effects at least, with a total temperature spread of a little over 100° F. In other words, you can get 10 effects in the same temperature spread ordinarily required for four effects. You get your increased heat conductivity without going to enormous pressures, and you get excellent operation. In an evaporator like that proposed the calculation shows that you will get 11.2 lbs. of water evaporated per pound of steam. In other words, assuming that you have 9 lbs. of steam evaporated per pound of coal, you get 100 lbs. of water evaporated per pound of coal. This means that you get more than two and a half times the evaporation per pound of coal that is done by ordinary multiple effect evaporation, and can thus build a plant for the evaporation of your sulphite liquor, so that the fuel value of this sulphite liquor and the lime which you recover (recovering it by the same process used at La Tuque) will pay for the plant in a year, and the fuel value in the recovery of lime should not only pay back your original investment, but should pay for labor, fixed charges and generous amortization charges, and still have a balance left.

Mr. E. R. Wilson: I should like to ask if your idea in using the spray nozzle was to carry the spray completely through the tubes during evaporation or to have it run through in a stream?

Mr. Moore: The spray is simply for distribution. If you plug the inlets of each tube so as to raise the liquor 12 ft. to the top tube, you must have a difference of exchange sufficient to create a corresponding pressure to overcome this 12 ft. of static head. According to the proposition outlined in this paper, the static head must be

reduced to an amount not over $\frac{1}{16}$ of an inch in any tube in the evaporator. The diameter of the tubes must be controlled by the nature of the liquid evaporated, because the boiling of whatever is in the tube must be sufficient to wet the whole surface of the tube. The kind of spray shown gives a method of uniform distribution and even though there are foreign matters of considerable size in the liquor, they will not plug the kind of nozzle shown. The spray is simply one of the methods of distribution that eliminates any static head on the evaporator.

The great heat conductivity may be shown by the following example: For instance assuming a uniform difference of 10° F. difference of exchange, with a liquor showing 10 per cent solids, we have 300 B.T.U. conducted per sq. ft. per degree of difference per hour, at 100° F. temperature level, while with the same difference of exchange and the same liquor we have 890 B.T.U. conducted per sq. ft. per degree difference per hour, at 210° F. temperature level. On sulphite liquor containing 20 per cent solids, using 10° difference of exchange, we find that we have 286 B.T.U. conducted per sq. ft. per degree of difference per hour, at 100° F. temperature level, while we have 830 B.T.U. conducted per sq. ft. per degree of difference per hour, at 210° F.

Using the same difference of exchange we find that with 1.30 per cent solids we have 264 B.T.U. conducted per sq. ft. per degree of difference per hour and there is a difference of exchange at a temperature level of 100° F., while if we have 690 B.T.U. conducted per sq. ft. per degree of difference per hour, there is a difference of exchange at a temperature level of 210° F. If the liquor contains 40 per cent solids we have 216 B.T.U. conducted per sq. ft. per degree of difference per hour, per difference of exchange at 100° F. temperature level, while if we have 536 B.T.U. conducted per sq. ft. per degree of difference per hour there is a difference of exchange at a temperature level of 210° F.; or if the liquor contains 50 per cent solids using about 10° difference of exchange, we find that we have 70 B.T.U. conducted per sq. ft. per degree of difference per hour, at a temperature level of 100° F., while we have 366 B.T.U. conducted per sq. ft. per degree of difference per hour at a temperature level of 210° F. For other differences of exchange and temperature levels you can consult the charts.

Mr. Wilson: Then you utilize only a small portion of the area of the tube?

Mr. Moore: No, I use the whole of it.

Mr. Wilson: Does the liquor go through in a spray?

Mr. Moore: Oh, you are referring to these pictures?

Mr. Wilson: Yes.

Mr. Moore: Those pictures were for the distribution of cold liquor, simply to show the work in the nozzle. That was cold liquor without any steam around it. That was to pick out the kind of a nozzle which would distribute evenly. If we could not find a nozzle which would distribute properly the whole scheme would go to pieces. The only nozzle which distributes the spray is the Spraco nozzle. This is the only one that we have been able to find that will distribute the liquor properly.

Dr. Ralph H. McKee: I understand that in the Swiss plants which are evaporating and burning their sulphite waste liquor, they are using a thermo-compressor as their first effect. This, I am told, is followed by ordinary multiple methods. Do you know how many they use?

Mr. Moore: I understand they have three in the multiple effect case, the first effect making four in all. I have gone into thermal compressing, but I was obliged to omit that to-day. There is no economy in thermal compression for this reason. You may economize a certain amount of steam but you can do the same thing in other ways. As your heat conductivity is an exact function of your temperature differences, and temperature level, when you take more heat around and conduct it through the tubes again, you have got to have the required heating surface to do it. Now do you want to put that whole heating surface into one effect, or into a number of effects where you can shut off one, and continue to run the other eight or nine, or whatever the number happens to be? There is no economy so far as installation is concerned, in thermal compression, and there are only a few cases where you have tremendously high coal and very cheap water power in which you can use the thermal compressor.

Dr. McKee: Of course that is somewhat the situation in Switzerland, where cheap water power can be had and coal is very high. You spoke of going to 50 per cent solids.

Mr. Moore: Yes.

Dr. McKee: They go much higher; they go to 80 per cent solids.

Mr. Moore: I don't see how they do that. Their sulphite liquor

must be different from what we are using. You will remember that I stated that the recovery of this liquor was based upon recovering it the way we were burning liquor in La Tuque. Now, there is a limit at which you can explode that liquor.

Dr. McKee: They are not exploding it at all.

Mr. Moore: I know, but the cheapest way to burn it is to explode it. We can explode the 50 per cent liquor and handle it economically. If you want to, in heating surface enough you can carry the liquor to a somewhat higher concentration. I don't believe you can carry our liquor up to 80 per cent because it is different from any other in the United States, but I don't doubt that there may be some sulphite liquors which might possibly have been concentrated to this extent or even higher, but they must have been different from any I have seen.

Dr. McKee: Have you tried, and if so, what difference have you found on explosion when you were using, 60 or 80 per cent rather than 50 per cent liquor?

Mr. Moore: I have not got my heat conductivity for 60 per cent liquor. In sulphate-sulphite liquor your heat conductivity at 100 degrees level will be about 75 B.T.U. On the other hand, if there is a temperature level around 200, you will get something like 300 B.T.U. of conductivity on the same difference, due to increased temperature level, making a difference of thousands of square feet in the surface. If you get down to 80 per cent liquor, even at enormously high temperatures, I would not expect that you would get a heat conductivity of more than 40 B.T.U. with a probability of less, owing to the concentration of the liquor itself and the difficulty of moving a liquor of such a high viscosity over the heating surface.

Dr. McKee: From the explosive process would you expect essentially any difference with the smaller amount—40 per cent instead of 50 per cent?

Mr. Moore: Of course the ideal would be to have 100 per cent sulphite in the explosion process. But the question of cost all comes into this thing, and it is primarily a question of cost anyway.

Dr. McKee: You would expect explosion effects with 20 or 40 per cent water as well as 50?

Mr. Moore: No, you have to have a certain volume of water which you can heat to a certain temperature, to give a sufficient explosive ratio. In other words, you are limited to temperatures which

you can deal with because in the first place, beyond this temperature it tends to polymerize, and after you get to certain places the process breaks down—so you are limited to the pressures at which you can heat it to explode it. If you had one pound of water and 10 pounds of water, you could store in the 10 pounds of water 10 times as much heat as in one pound, so as to give very much higher ratios. For burning, however, the percentage of combustibles should be as high as possible without destroying the efficiency of the explosion.

Dr. McKee: In your opinion will 60 per cent be essentially different from 50 per cent water? Speaking from that side of the question, what would you consider a reasonable limit?

Mr. Moore: I should say about 50 or 55 per cent is a reasonable limit. It depends on the relation between organic solids and inorganic solids. In other words, you can handle a higher percentage of inorganic solids than of organic solids. We have been conducting this operation on a large scale, and the maximum efficiency was reached at between 50 and 55 per cent solids. In relation to the chartered results, I might add that after my original experiments the conductivities looked so improbable that we built a small evaporator of this type to see if we could get the results. The evaporator is still running and producing almost identically the results shown in these figures, but has 111 times the capacity of the original evaporator. We operate in some cases with only 7° difference and yet get a heat conductivity which is enormous. You will see that by the charts. This is a paper which is not easily delivered because there are so many variables, and I think you can get more out of it by reading it.

A Member: How do you determine the heat conductivity? Under what conditions was that determined?

Mr. Moore: The heat conductivity is determined as follows: you will note the square feet of heating surface in that evaporator. You start with a certain percentage of liquor, and that is known. Now we will arbitrarily establish a 5° or 10° difference of exchange so that the heating surface on the outside will be 10° hotter than the heat on the inside of the tubes. That is also known. The temperature level we try to establish. There may be a variation of half a degree or something of that sort so that you get your pressures. You don't rely on the thermometers for your steam pressure because of the fact that steam coming from a hot source may have superheat.

So that while you have a thermometer you still have to determine the saturated temperature by the pressure of that steam as shown by a mercury column, and the given pressure of mercury will correspond to a given boiling point of water and corresponding saturated temperature of the steam. Having those factors you measure the amount of liquor going in and going out, the amount of drip going out, and the temperature. The temperature of the steam going in and the temperature of the steam going out, and the amount of evaporation are also measured.

One can get the amount of heat conducted in three ways:

(1) Having the amount of condensed steam, and knowing the pressure, temperature and quality of the inlet steam, temperature and quality of the condensed steam, and the amount of radiation, we can subtract from the total heat the sum of the heat in the condensed steam and the heat lost by radiation, and the difference will be the heat conducted through the tube.

(2) Knowing the percentage of solids in the entering and the exit liquor, their respective temperatures and the amounts, we can tell the amount of water evaporated and the heat in such water evaporated. The heat in the steam evaporated at observed pressure, minus the difference between the heat in the liquor entering and the heat in the liquor leaving, will be the heat conducted through the tubes.

(3) Knowing the condensate from the liquor as measured, which is the measured amount of evaporated steam condensed in the condenser, we can figure the heat in the steam evaporated and subtract therefrom the difference in the heat between the measured amount of liquor entering and the measured amount of liquor leaving, and the result will be the heat conducted through the tubes.

It is unnecessary to say that the above refers only to a simple, single stage in evaporation. It will thus be seen that there are three ways of checking up how much heat is conducted. If then you find your logarithmic mean of temperatures and divide the heat conducted by the product of the logarithmic mean and the heating surface, you will get the heat conducted per degree of difference of exchange per sq. ft. through the tubes, which is the figure in the tables marked "K." After determining these figures at one percentage the percentages can be changed and the heat conductivities determined again. After having gone through the determinations of the differ-

ent percentages of liquor at one temperature level, the temperature level is changed and the experiments are repeated. These charts represent the results as obtained from thousands of experiments.

THE MEMBER: Were they determined on a large scale?

MR. MOORE: First on a tube three inches in diameter and 25 feet long, as being easily controlled. The results were so startling that we had some hesitancy, some doubt whether they were true. We could not see an error but we had some difficulty in believing them to be true. Then we built an evaporator with 111 tubes and tried it out and obtained practically the same results, so we feel sure of the accuracy of the data as shown by the charts. It is now on a workable, semi-commercial scale.

MR. R. T. HASLAM: Did you say that the conductivity of steam with a small amount of air will vary with the acidity, and that the small amount of acid will increase the heat conductivity?

MR. MOORE: A very slight trace of acid or a very slight trace of alkali will make a great change in the heat conductivity, in the No. 1 effect. If the other effects become acid or alkaline, you don't have that result. The inside of the tubes are taken care of by the liquor itself. The steam from the boiler on the outside of the tubes in the first effect causes the formation of this thin film of lime suboxide, or whatever it is. But that is what interferes with the heat.

A MEMBER: Are you talking of steam going from the boiler into the first effect?

MR. MOORE: Yes, I am talking of steam into the first effect, and you don't have it on the inside of the tubes. It is steam from the boiler that forms this suboxide on the outside of the tubes, which is a very poor conductor, and you will vary the coefficient of heat transfer in shutting down overnight, if you don't look out. That is why the thermal compressor comes in handy, because it takes some of the steam that is mixed with acid or alkali, and mixes it with other steam on the outside of the tube for the purpose of presenting a change in conductivity due to the formation of scale. It does not tend to increase in thickness but tends to keep the efficiency down and you must have the evaporator a good deal bigger unless you have something of this sort. We never obtained a higher result than on pure water.

(Discussion closed.)

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